TP 4192E

M.V. ARCTIC BOW REDESIGN

STUDY - PHASE I

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March 1983

The contents of this report reflect the views of the authors and not necessarily the official views or policies of the Transportation Development Centre.

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17. Abstract

This working paper reports on the first phase of a study concerned with the redesign of the bow of the icebreaking bulk cargo carrier M.V. Arctic. The primary objective of the study is to improve the operational capability of the M.V. Arctic so as to permit an increase in the number of annual northern voyages and the possible opening of new trading routes for the vessel.

Environmental criteria of the routes of the M.V. Arctic's voyages were studied and predictor equations developed to analyze the effects of various bow form parameters on the icebreaking resistance of the hull. The results of these and related analyses were used in a design process that produced five hull forms. The predicted resistance in level of each of these was calculated and two bow forms showing promise of improved icebreaking efficiency were chosen for further testing.

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17. Résumé

Ce rapport rend compte des travaux constituant la phase I d'un projet visant la modification de la proue de l'Arctic, vraquier brise-glace, dont on veux accroître les aptitudes de manière à autoriser un plus grand nombre de périples annuels dans les eaux arctiques et à lui permettre d'emprunter de nouvelles routes commerciales.

Il définit les critères qui ont été appliqués concernant la prévention de la pollution des eaux arctiques et donnes les expressions mathématiques permettant de prédire et d'analyser l'effet des divers paramètres utilisés dans le calcul de la résistance de la coque aux glaces. Il présente cinq différentes carènes qui ont pu être dégagées grâce aux travaux décrits et à des travaux connexes. Enfin, il montre comment la résistance de chacune de ces carènes à une glace d'épaisseur uniforme a pu être calculée, et comment il a été procédé pour sélectionner les deux géométries les plus prometteuses.

18. Mots-clés Etude d'une proue brise-glace, routes de navigation arctique, calcul de la résistance aux glaces		19. Diffusion Le CDT dispose d'un nombre limité d'exemplaires	
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1.0 INTRODUCTION

The M.V. ARCTIC is a 28,000 DWT bulk carrier which, during the summer and fall months, carries lead and zinc concentrates between mine sites in the Northwest Territories and Europe. The M.V. ARCTIC is classed as an Arctic Class 2 vessel in accordance with the Canadian Arctic Shipping Pollution Prevention Regulations (CASPPR), and is fitted with an ice breaking bow.

Following substantial full scale testing of the M.V. ARCTIC it was realised that the vessel's operating capability could be improved by redesigning the bow.

As a result of these tests and data analysis, the Transportation Development Centre (TDC) engaged Melville Shipping Ltd. to develop several new designs of the bow so that they could select two for subsequent model testing and in depth analysis.

This report represents the work required to develop the bow forms described above. The report is divided into three main sections.

The first is an environmental study of the areas through which the M.V. ARCTIC passes on its way to the mine sites in the Northwest Territories. The study includes descriptions of the extent, type and thickness of the ice expected to be encountered during different months of the year.

The second part of the report is the development of an equation capable of predicting the relative merits of a number of bow forms on a vessel such as the M.V. ARCTIC. The predictor equation obtained is based on a number of published equations modified to correctly reflect the data collected during the M.V. ARCTIC full scale tests.

The third part of the report is the development of a number of modified bow forms that enable the vessel to improve its ice breaking efficiency whilst still maintaining its open water efficiency.

The work was to be done as quickly as possible and forms the first part of a larger document which will include the work done in this report together with model testing in ice and open water.

2.0 ENVIRONMENTAL CRITERIA

2.1 Ice Infested Waters

During the ARCTIC's northern voyages the vessel may pass through zones 6, 9, 10 and 13, as defined by the Arctic Waters Pollution Prevention Regulations. Figure 1 and Table 1 define these areas and the months during which, as an Arctic Class 2 vessel, the ARCTIC can operate.

Much of the information in this part of the report has been extracted from the Melville Shipping Ltd. report "M.V. ARCTIC Northern Routing Environment" and further detail on specific ice conditions can be obtained from the report (ref. 1).

It should also be noted here that the values for environmental data given in this section represents median, or typical conditions that may be encountered (i.e. 50 percentile level, or half the time the conditions will be more severe than this).

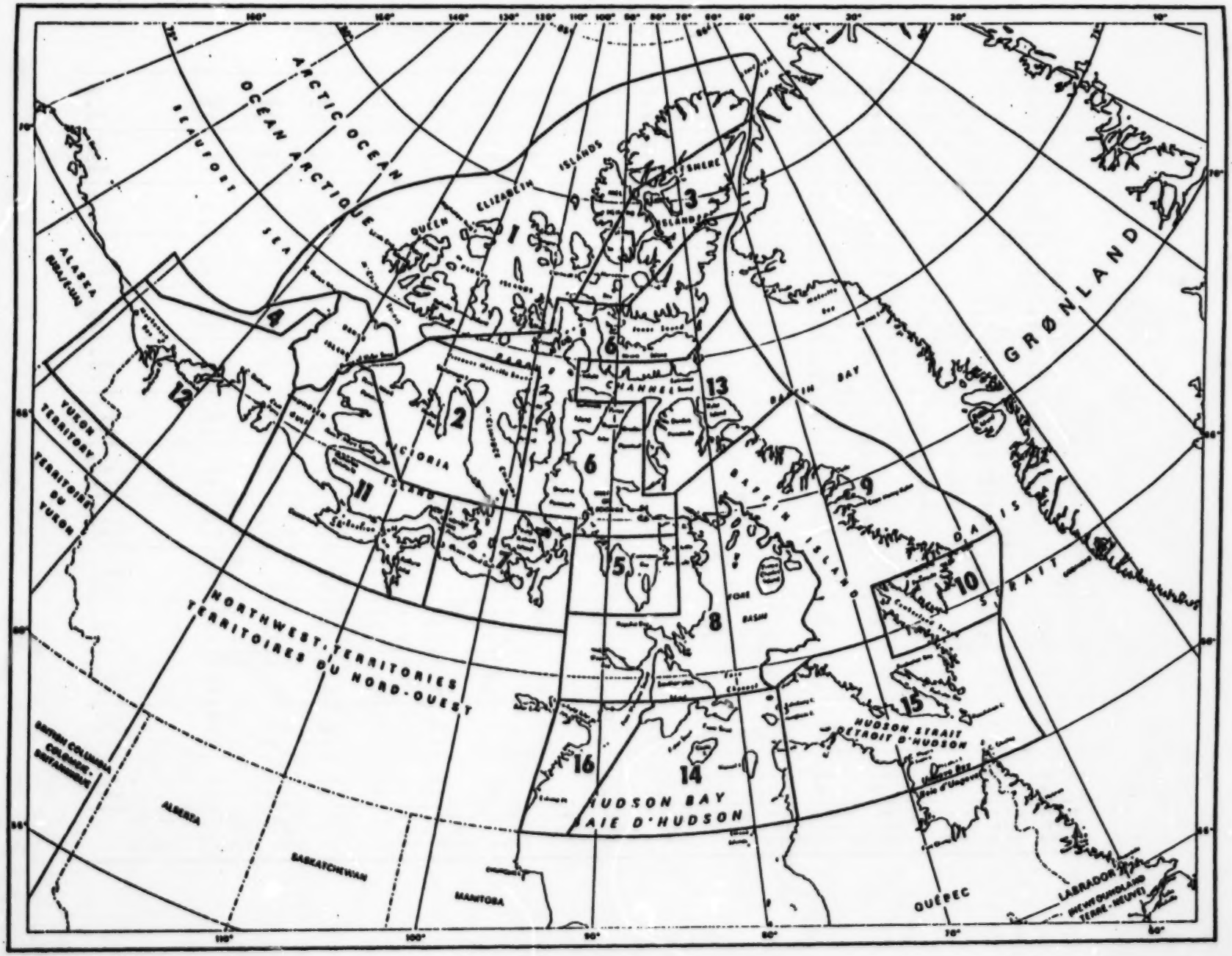
No attempt has been made to account for extremes and/or regional or local or annual variations.

The routes taken by the ARCTIC on her passage to the Nanisivik mine on Baffin Island and the Polaris mine on Little Cornwallis Island are shown in Figures 2 and 3, during specific months of the year. These routes should only be considered as illustrative, the actual route will depend on navigational criteria.

From Figures 2 and 3, it can be seen that the vessel's route is slightly different depending on the time of year. During the early months, the route taken is along the eastern seaboard of Davis Strait and Baffin Bay avoiding the higher ice concentrations in the west. Later in the year as this ice clears, the vessel can take a more direct route to Lancaster Sound. From Baffin Bay the route enters Lancaster Sound and proceeds to either Admiralty Inlet and the Nanisivik mine terminal, or further west through Lancaster Sound and Barrow Strait to McDougall Sound and the Polaris mine terminal.

From an analysis of these routes, median ice conditions can be deduced, and these are presented in Tables 2 - 13. It can be seen from these figures that the thickest ice will be encountered in May and June in Admiralty Inlet and McDougall Sound.

The ice encountered in the earlier months tends to be thicker but generally weaker than the ice found in the later months. The reduction in strength in July is due to the initial melting of the ice at the grain boundaries rather than at the water/ice or ice/air interface. This has the effect of reducing the ice strength without appreciably affecting the ice thickness.

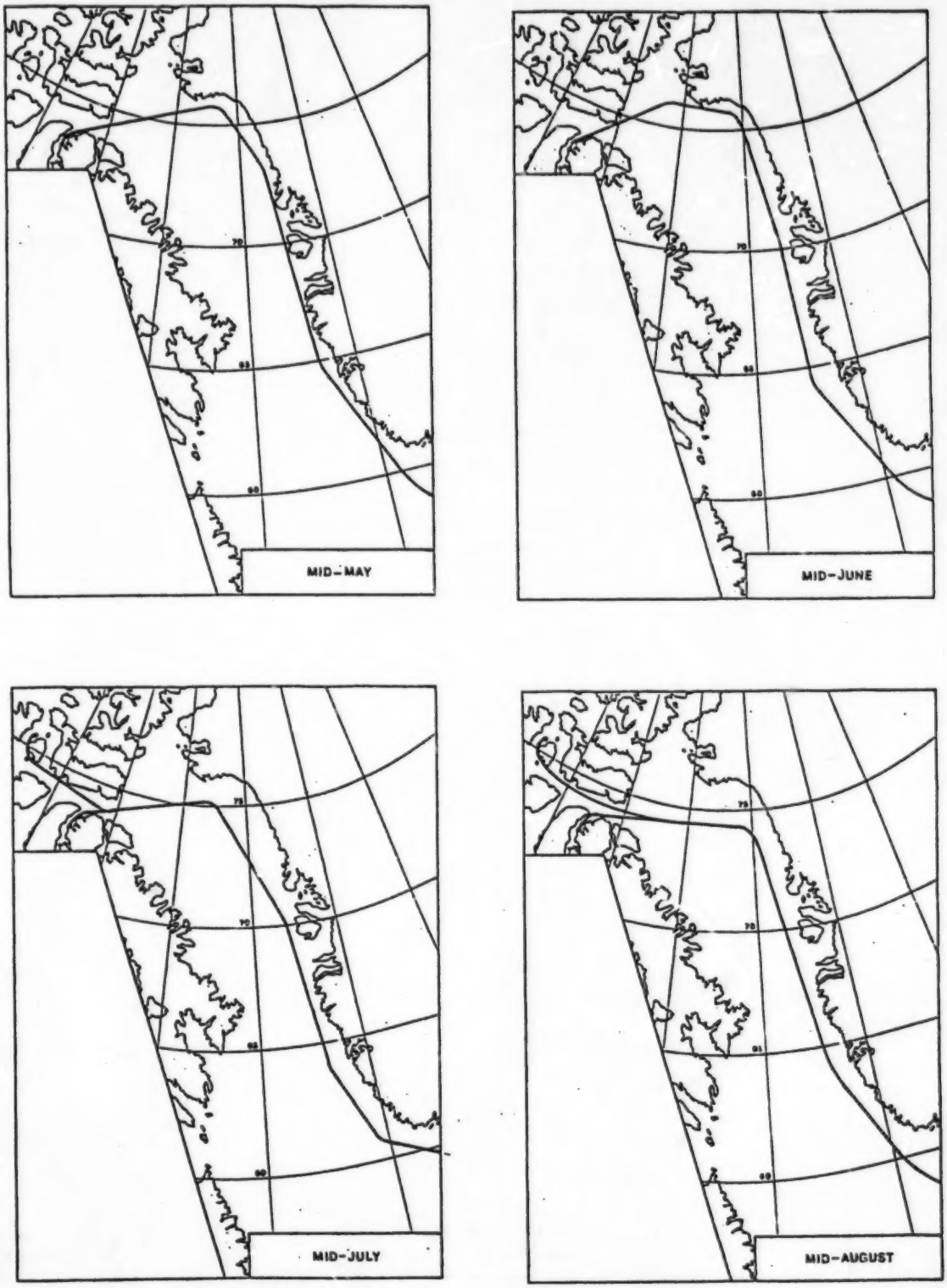


SHIPPING SAFETY CONTROL ZONES
Figure 1

Column I Category	Column II Zone 1	Column III Zone 2	Column IV Zone 3	Column V Zone 4	Column VI Zone 5	Column VII Zone 6	Column VIII Zone 7	Column IX Zone 8	Column X Zone 9	Column XI Zone 10	Column XII Zone 11	Column XIII Zone 12	Column XIV Zone 13	Column XV Zone 14	Column XVI Zone 15	Column XVII Zone 16
Arctic Class 10 1.	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year
Arctic Class 8 2.	Jul. 1 to Oct. 15	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year
Arctic Class 7 3.	Aug. 1 to Sept. 30	Aug. 1 to Nov. 30	Jul. 1 to Dec. 31	Jul. 1 to Dec. 15	Jul. 1 to Dec. 15	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year	All Year
Arctic Class 6 4.	Aug. 15 to Sept. 15	Aug. 1 to Oct. 31	Jul. 15 to Nov. 30	Jul. 15 to Nov. 30	Aug. 1 to Oct. 15	Jul. 15 to Feb. 28	Jul. 1 to Mar. 31	Jul. 1 to Mar. 31	All Year	All Year	Jul. 1 to Mar. 31	All Year	All Year	All Year	All Year	All Year
Arctic Class 4 5.	Aug. 15 to Sept. 15	Aug. 15 to Oct. 15	Jul. 15 to Oct. 31	Jul. 15 to Nov. 15	Aug. 15 to Sept. 30	Jul. 20 to Dec. 31	Jul. 15 to Jan. 15	Jul. 15 to Jan. 15	Jul. 10 to Mar. 31	Jul. 10 to Feb. 28	Jul. 5 to Jan. 15	June 1 to Jan. 31	June 1 to Feb. 15	June 15 to Feb. 15	June 15 to Mar. 15	June 1 to Feb. 15
Arctic Class 3 6.	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	Jul. 25 to Oct. 15	Jul. 20 to Nov. 5	Aug. 20 to Sept. 25	Aug. 1 to Nov. 30	Jul. 20 to Dec. 15	Jul. 20 to Dec. 31	Jul. 20 to Jan. 20	Jul. 15 to Jan. 25	Jul. 5 to Dec. 15	June 10 to Dec. 31	June 10 to Dec. 31	June 20 to Jan. 10	June 20 to Jan. 31	June 5 to Jan. 10
Arctic Class 2 7.	No Entry	No Entry	Aug. 15 to Sept. 30	Aug. 1 to Oct. 31	No. Entry	Aug. 15 to Nov. 20	Aug. 1 to Nov. 20	Aug. 1 to Nov. 30	Aug. 1 to Dec. 20	Jul. 25 to Dec. 20	Jul. 10 to Nov. 20	June 15 to Dec. 5	June 25 to Nov. 15	June 25 to Dec. 10	June 25 to Dec. 20	June 10 to Dec. 10
Arctic Class 1A 8.	No Entry	No Entry	Aug. 20 to Sept. 15	Aug. 20 to Sept. 30	No Entry	Aug. 25 to Oct. 31	Aug. 10 to Nov. 5	Aug. 10 to Nov. 20	Aug. 10 to Dec. 10	Aug. 1 to Dec. 10	Jul. 15 to Nov. 10	Jul. 1 to Nov. 10	Jul. 15 to Oct. 31	Jul. 1 to Nov. 30	Jul. 1 to Dec. 10	June 20 to Nov. 30
Arctic Class 1 9.	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 25 to Sept. 30	Aug. 10 to Oct. 15	Aug. 10 to Oct. 31	Aug. 10 to Oct. 31	Aug. 1 to Oct. 31	Jul. 15 to Oct. 20	Jul. 1 to Oct. 31	Jul. 15 to Oct. 15	Jul. 1 to Nov. 30	Jul. 1 to Nov. 30	June 20 to Nov. 15
Type A 10.	No Entry	No Entry	Aug. 20 to Sept. 10	Aug. 20 to Sept. 20	No Entry	Aug. 15 to Oct. 15	Aug. 1 to Oct. 25	Aug. 1 to Nov. 10	Aug. 1 to Nov. 20	Jul. 25 to Nov. 20	Jul. 10 to Oct. 31	June 15 to Nov. 10	June 25 to Oct. 22	June 25 to Nov. 30	June 25 to Dec. 5	June 20 to Nov. 20
Type B 11.	No Entry	No Entry	Aug. 20 to Sept. 5	Aug. 20 to Sept. 15	No Entry	Aug. 25 to Sept. 30	Aug. 10 to Oct. 15	Aug. 10 to Oct. 31	Aug. 10 to Oct. 31	Aug. 1 to Oct. 31	Jul. 15 to Oct. 20	Jul. 1 to Oct. 25	Jul. 15 to Oct. 15	Jul. 1 to Nov. 30	Jul. 1 to Nov. 30	June 20 to Nov. 10
Type C 12.	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 25 to Sept. 25	Aug. 10 to Oct. 10	Aug. 10 to Oct. 25	Aug. 10 to Oct. 25	Aug. 1 to Oct. 25	Jul. 15 to Oct. 15	Jul. 1 to Oct. 25	Jul. 15 to Oct. 10	Jul. 1 to Nov. 25	Jul. 1 to Nov. 25	June 25 to Nov. 10
Type D 13.	No Entry	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 10 to Oct. 5	Aug. 15 to Oct. 20	Aug. 15 to Oct. 20	Aug. 5 to Oct. 20	Jul. 15 to Oct. 10	Jul. 1 to Oct. 20	Jul. 20 to Sept. 30	Jul. 10 to Nov. 10	Jul. 5 to Nov. 10	Jul. 1 to Oct. 31
Type E 14.	No Entry	No Entry	No Entry	No Entry	No Entry	No Entry	Aug. 10 to Sept. 30	Aug. 20 to Oct. 20	Aug. 20 to Oct. 15	Aug. 10 to Oct. 20	Jul. 15 to Sept. 30	Jul. 1 to Oct. 20	Aug. 15 to Sept. 20	Jul. 20 to Oct. 31	Jul. 20 to Nov. 5	Jul. 1 to Oct. 31

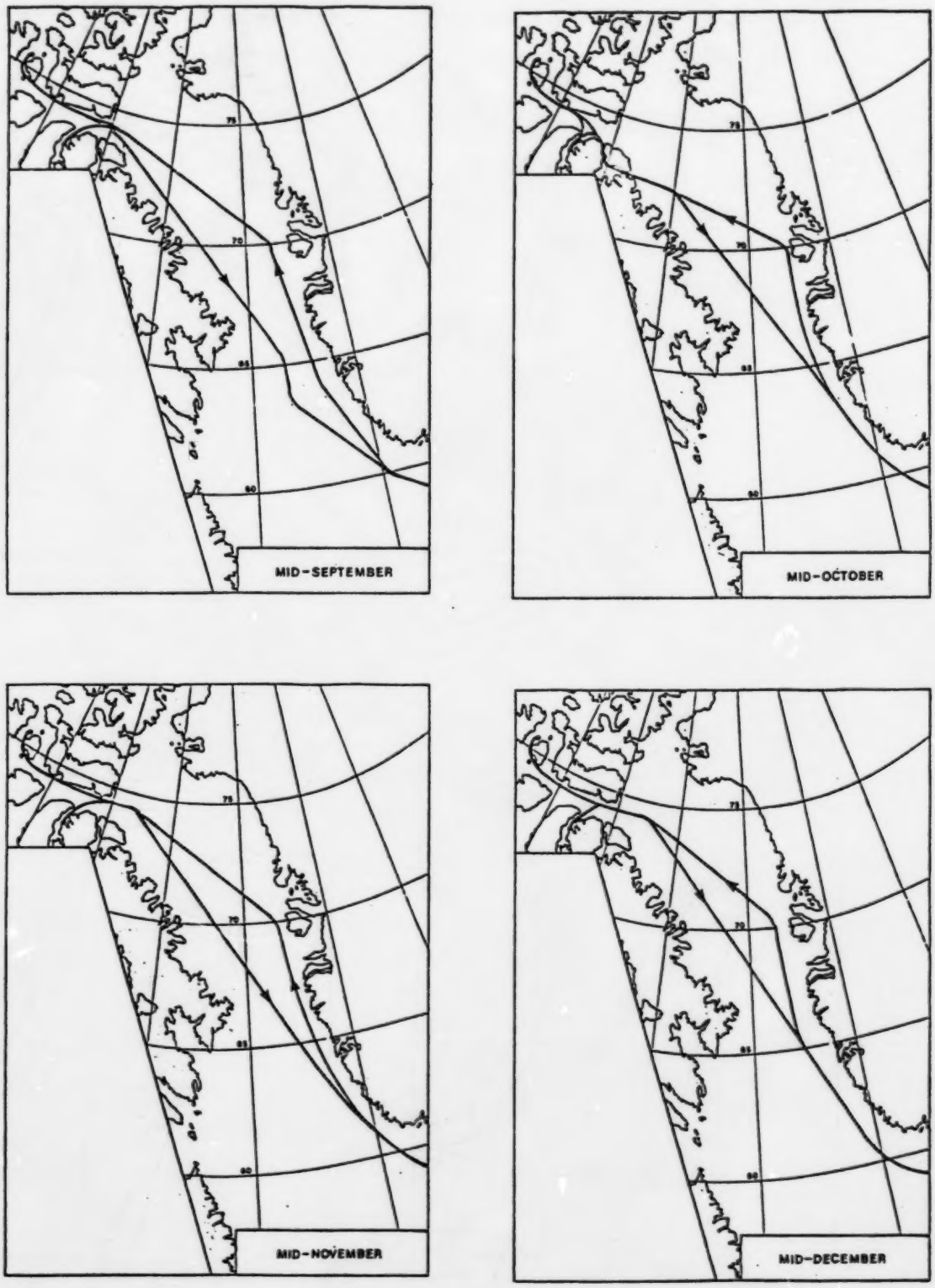
Period of Navigation for the Shipping Safety Control Zones

Table 1



NORTHERN ROUTE OF M.V. ARCTIC

Figure 2



NORTHERN ROUTE OF M.V. ARCTIC

Figure 3

PERIOD - MID MAY; NORTH AND SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1175	-	-	-	-	-	1175
VERY OPEN PACK	-	-	-	-	-	-	-
OPEN PACK	SOME STORIS	-	-	-	-	-	-
CLOSE PACK	-	-	-	-	-	-	-
VERY CLOSE PACK	-	1200	150	270	-	-	1350-N 1470-P
CONSOLIDATED	-	-	-	150	100	160	100-N 310-P
OLD ICE[1]	-	-	-	-	-	-	-
ICE THICKNESS m	-	1.3-1.6	1.8-2.0	1.8-2.0	1.75-2.0	2.0-2.2	**
FLEXURAL STRENGTH kPa[2]	-	450-500	500	500	500	550	**
COMPRESSIVE STRENGTH MPa[3]	-	10-15	17.5-20.0	17.5-20.0	17.5-20.0	20	**

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 2

PERIOD - MID JUNE: NORTH AND SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
	—		TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1200	500	70	X	-	X	1770
VERY OPEN PACK	-	-	70	X	-	X	70
OPEN PACK	SOME STORIS	60	-	X	-	X	60
CLOSE PACK	-	340	-	X	-	X	340
VERY CLOSE PACK	-	300	-	X	-	X	300
CONSOLIDATED	-	-	-	X	100	X	100
OLD ICE[1]	-	-	-	-	-	X	X
ICE THICKNESS m	-	0.7-1.0	0.75	X	1.75-2.0	X	**
FLEXURAL STRENGTH kPa[2]	-	350	-	X	450	X	**
COMPRESSIVE STRENGTH MPa[3]	-	6	-	X	13	X	**

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 3

PERIOD - MID JULY; NORTH OR SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1300	750	140	300	-	-	2190-N 2350-P
VERY OPEN PACK	-	150	-	-	-	-	150
OPEN PACK	SOME STORIS	200	-	-	-	-	200
CLOSE PACK	-	-	-	130	-	-	130-P
VERY CLOSE PACK	-	-	-	-	-	45	45-P
CONSOLIDATED	-	-	-	-	100*	135	100-N 135-P
OLD ICE[1]	-	-	-	-	-	-	-
ICE THICKNESS m	-	-	-	1.2-1.5	1.2-1.5	1.5-1.75	**
FLEXURAL STRENGTH kPa[2]	-	-	-	200-300	200-300	300-400	**
COMPRESSIVE STRENGTH MPa[3]	-	-	-	10	6	15	**

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* ASSUMING NO PREVIOUS VOYAGE, BROKEN CHANNEL OTHERWISE.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 4

PERIOD - MID AUGUST; NORTH OR SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1200	1100	140	430	100	-	2540-N 2400-P
VERY OPEN PACK	-	-	-	-	-	-	-
OPEN PACK	-	-	-	-	-	-	-
CLOSE PACK	-	-	-	-	-	25	25-P
VERY CLOSE PACK	-	-	-	-	-	135	135-P
CONSOLIDATED	-	-	-	-	-	-	-
OLD ICE[1]	-	-	-	-	-	-	-
ICE THICKNESS m	-	-	-	-	-	1.0-1.2	**
FLEXURAL STRENGTH kPa[2]	-	-	-	-	-	200-300	**
COMPRESSIVE STRENGTH MPa[3]	-	-	-	-	-	6	**

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 5

PERIOD - MID SEPTEMBER; NORTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1200	920	140	420	100	160	2360-N 2700-P
VERY OPEN PACK	-	-	-	-	-	-	-
OPEN PACK	-	-	-	-	-	-	-
CLOSE PACK	-	-	-	-	-	-	-
VERY CLOSE PACK	-	-	-	-	-	-	-
CONSOLIDATED	-	-	-	-	-	-	-
OLD ICE[1]	-	-	-	-	-	12	-
ICE THICKNESS m	-	-	-	-	-	-	X
FLEXURAL STRENGTH kPa[2]	-	-	-	-	-	-	X
COMPRESSIVE STRENGTH MPa[3]	-	-	-	-	-	-	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 6

PERIOD - MID SEPTEMBER; SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1350	670	140	420	100	160	2260-N 2600-P
VERY OPEN PACK	-	-	-	-	-	-	-
OPEN PACK	-	-	-	-	-	-	-
CLOSE PACK	-	-	-	-	-	-	-
VERY CLOSE PACK	-	-	-	-	-	-	-
CONSOLIDATED	-	-	-	-	-	-	-
OLD ICE[1]	-	-	-	-	-	12	-
ICE THICKNESS m	-	-	-	-	-	-	X
FLEXURAL STRENGTH kPa[2]	-	-	-	-	-	-	X
COMPRESSIVE STRENGTH MPa[3]	-	-	-	-	-	-	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 7

PERIOD - MID OCTOBER; NORTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND TO NANISIVIK	LANCASTER SOUND SOUND TO POLARIS	ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
LENGTH - km OPEN WATER	1200	700	-	-	-	-	1900
VERY OPEN PACK	-	45	-	-	-	-	45
OPEN PACK	-	45	-	-	-	-	45
CLOSE PACK	-	-	-	-	-	-	-
VERY CLOSE PACK	-	260	65	420	120	160	445-N 840-P
CONSOLIDATED	-	-	-	-	-	-	-
OLD ICE[1]	-	-	-	-	-	12	-
ICE THICKNESS m	-	.2	.2*	.2*	.1	.15	X
FLEXURAL STRENGTH kPa[2]	-	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	X
COMPRESSIVE STRENGTH MPa[3]	-	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* SOME OLD ICE, LOW STRENGTH.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 8

PERIOD - MID OCTOBER; SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND TO NANISIVIK	LANCASTER SOUND SOUND TO POLARIS	ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
LENGTH - km OPEN WATER	1350	450	-	-	-	-	1800
VERY OPEN PACK	-	45	-	-	-	-	45
OPEN PACK	-	45	-	-	-	-	45
CLOSE PACK	-	-	-	-	-	-	-
VERY CLOSE PACK	-	260	65	420	120	160	445-N 840-P
CONSOLIDATED	-	-	-	-	-	-	-
OLD ICE[1]	-	-	-	-	-	12	-
ICE THICKNESS m	-	.2	.2*	.2*	.1	.15	X
FLEXURAL STRENGTH kPa[2]	-	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	X
COMPRESSIVE STRENGTH MPa[3]	-	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	VERY WEAK	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* SOME OLD ICE, LOW STRENGTH.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 9

PERIOD - MID NOVEMBER; NORTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1250	-	-	-	-	-	1250
VERY OPEN PACK	-	100	-	-	-	-	100
OPEN PACK	-	-	-	-	-	-	-
CLOSE PACK	-	850	-	-	-	-	850
VERY CLOSE PACK	-	-	160	420	-	100	160-N 520-P
CONSOLIDATED	-	-	-	-	100	60	100-N 60-P
OLD ICE[1]	-	26	-	-	-	-	-
ICE THICKNESS m	-	.2-.4	.5	.5	.3	.5-.6	X
FLEXURAL STRENGTH kPa[2]	-	WEAK	300-400	300-400	400	400	X
COMPRESSIVE STRENGTH MPa[3]	-	WEAK	18*	18*	5-10	10	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* OLD ICE PRESENT, PARTICULARLY AT ENTRANCE TO LANCASTER SOUND.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 10

PERIOD - MID NOVEMBER; SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	1100	-	-	-	-	-	1100
VERY OPEN PACK	130	-	-	-	-	-	130
OPEN PACK	-	-	-	-	-	-	-
CLOSE PACK	130	800	-	-	-	-	930
VERY CLOSE PACK	-	-	160	420	-	100	160-N 520-P
CONSOLIDATED	-	-	-	-	100	60	100-N 60-P
OLD ICE[1]	-	26	-	-	-	-	-
ICE THICKNESS m	.1	.2-.4	.5	.5	.3	.5-.6	X
FLEXURAL STRENGTH kPa[2]	VERY WEAK	WEAK	300-400	300-400	400	400	X
COMPRESSIVE STRENGTH MPa[3]	VERY WEAK	WEAK	18*	18*	5-10	10	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* OLD ICE PRESENT, PARTICULARLY AT ENTRANCE TO LANCASTER SOUND.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 11

PERIOD - MID DECEMBER; NORTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	740	-	-	-	-	-	740
VERY OPEN PACK	150	-	-	-	-	-	150
OPEN PACK	280	500	-	-	-	-	780
CLOSE PACK	-	460	-	-	-	-	460
VERY CLOSE PACK	-	-	160	420	-	100	160-N 520-P
CONSOLIDATED	-	-	-	-	100**	60	100-N 60-P
OLD ICE[1]	-	-	-	-	-	-	-
ICE THICKNESS m	-	.75	0.8-0.9	0.8-0.9	0.65	0.9	X
FLEXURAL STRENGTH kPa[2]	-	300-400	450-550	450-550	450-550	550	X
COMPRESSIVE STRENGTH MPa[3]	-	12.5-15	15*	15*	15	15-17.5	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* OLD ICE PRESENT, PARTICULARLY AT ENTRANCE TO LANCASTER SOUND.

** REFROZEN CHANNEL IF USED IN MID NOVEMBER.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 12

PERIOD - MID DECEMBER; SOUTH BOUND

	DAVIS STRAIT	BAFFIN BAY	LANCASTER SOUND SOUND		ADMIRALTY INLET	BARROW STRAIT + McDOUGALL SOUND	TOTAL
			TO NANISIVIK	TO POLARIS			
LENGTH - km OPEN WATER	725	-	-	-	-	-	725
VERY OPEN PACK	130	-	-	-	-	-	130
OPEN PACK	-	-	-	-	-	-	-
CLOSE PACK	385	410	-	-	-	-	795
VERY CLOSE PACK	-	400	160	420	-	100	560-N 920-P
CONSOLIDATED	-	-	-	-	100**	60	100-N 60-P
OLD ICE[1]	-	-	-	-	-	-	-
ICE THICKNESS m	.5	.75	0.8-0.9	0.8-0.9	0.65	0.9	X
FLEXURAL STRENGTH kPa[2]	90-350	300-400	450-550	450-550	450-550	550	X
COMPRESSIVE STRENGTH MPa[3]	12.5	12.5-15	15*	15*	15	15-17.5	X

1. LENGTH CALCULATED BY X MEDIAN AMOUNT OF OLD ICE BY ROUTE LENGTH IN THAT AREA - NO MANEOUVRING ACCOUNTED FOR.
2. MEAN FLEXURAL STRENGTH USING BEAM TEST (ESTIMATED).
3. MEAN MAXIMUM CONFINED COMPRESSIVE STRENGTH USING FENCO BORE JACK (ESTIMATED).

* OLD ICE PRESENT, PARTICULARLY AT ENTRANCE TO LANCASTER SOUND.

** REFROZEN CHANNEL IF USED IN MID NOVEMBER.

N = NANISIVIK P = POLARIS

Median Ice Conditions
Table 13

Consolidated ice only occurs in the areas considered in Admiralty Inlet and Barrow Strait/McDougall Sound, during May, June and July. However, during July the ice is rotten with many melt pools. Old ice may occur in limited amounts and could cause some navigational problems. Highly rafted or ridged ice may also occur during these months in varying amounts in the northwest corner of Baffin Bay, Lancaster Sound and Barrow Strait.

The occurrences of rafted or ridged ice will be highest in May and June in Baffin Bay, May, June, July, November and December in Barrow Strait, and November and December in Lancaster Sound. Their extent will be in the order of 2-3 tenths.

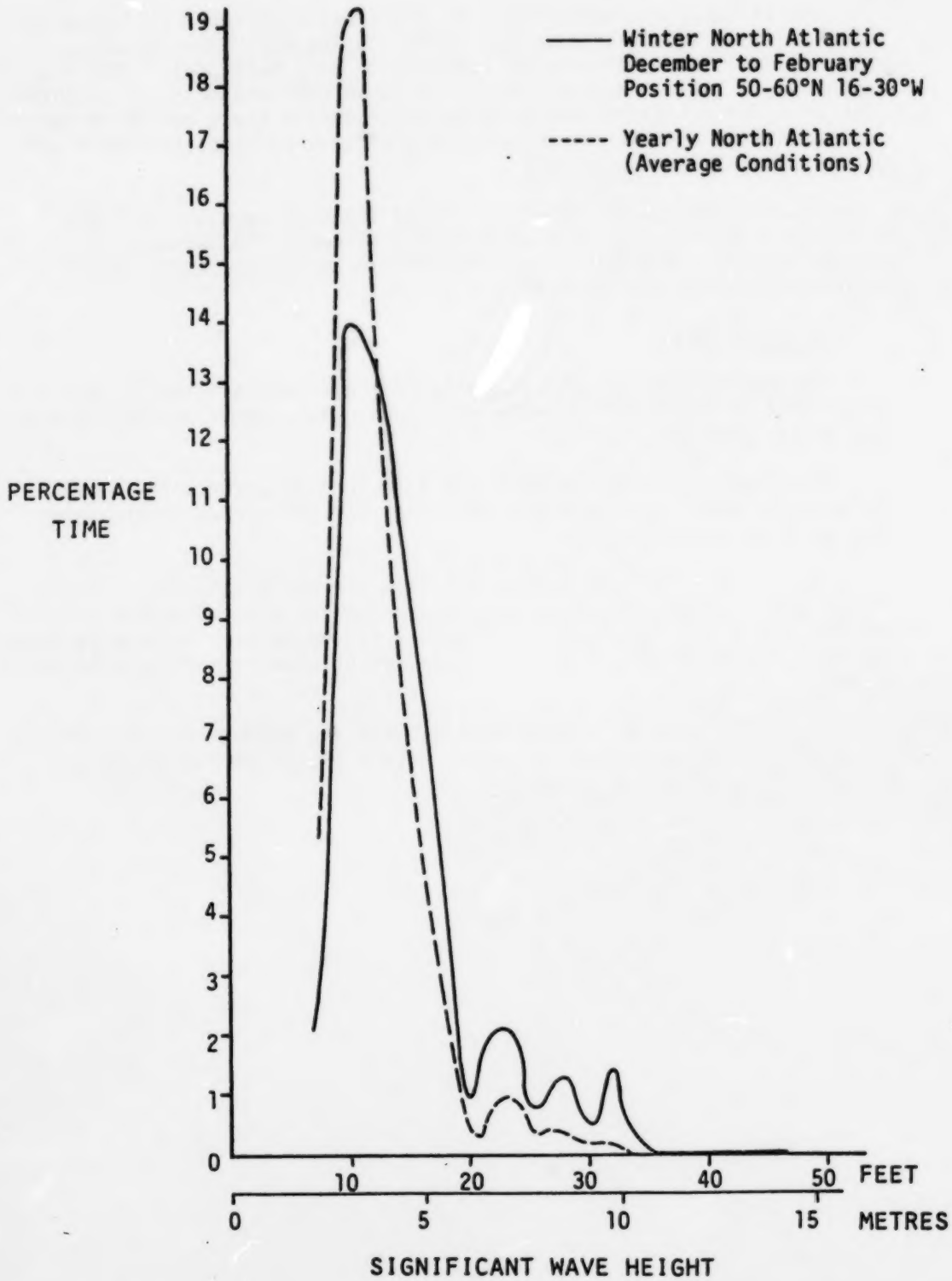
2.2 Open Water

The ARCTIC will spend a majority of the voyage sailing in open water both in the North Atlantic and, during the summer months, through the Arctic regions.

The design criteria to be taken into consideration with regard to the open water operation are both the size and period of the waves likely to be encountered.

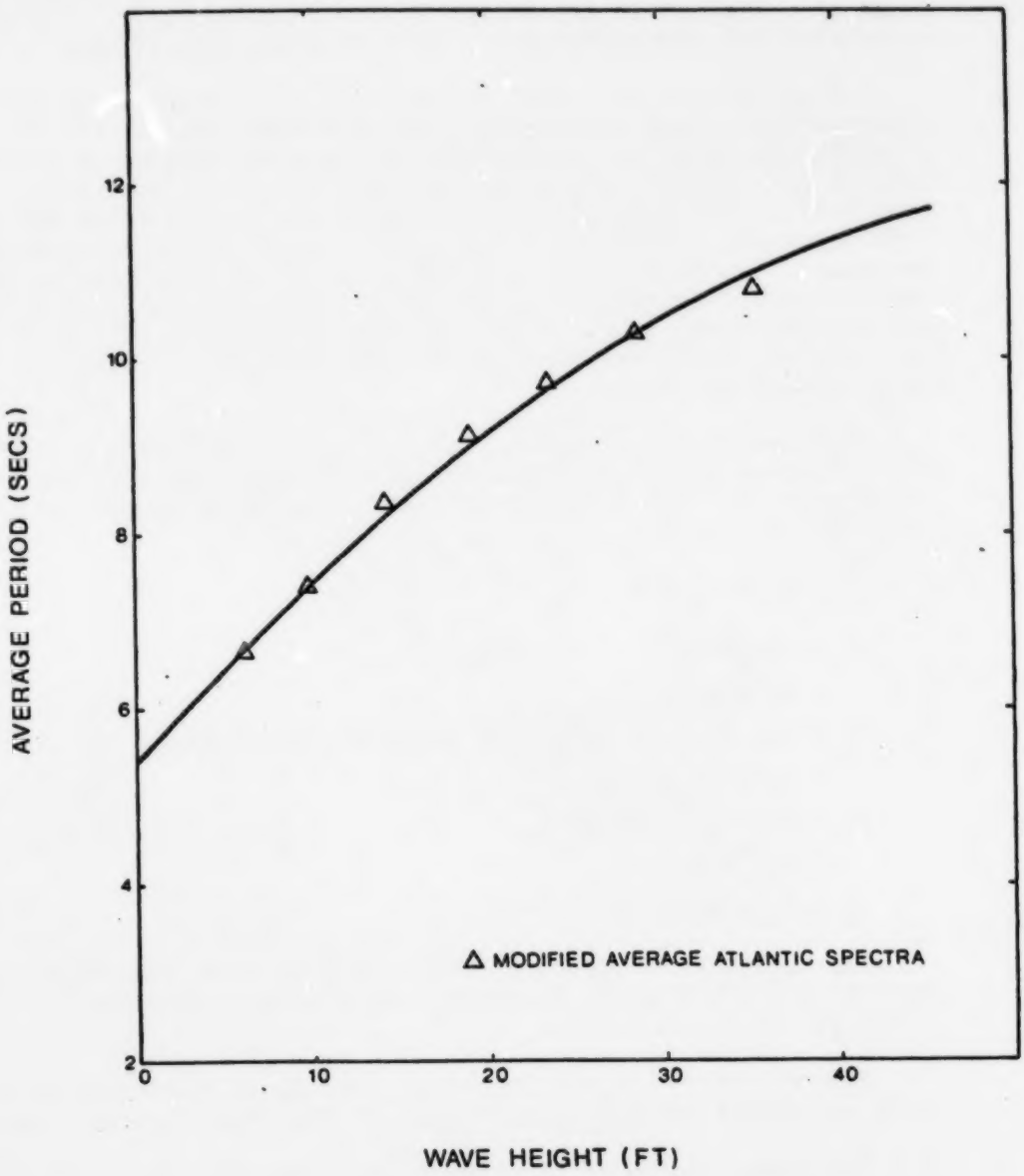
These values will be most onerous in the North Atlantic. Significant wave heights and percentage occurrence for a North Atlantic sea spectra are shown in Figure 4. Figure 4 can be related to wave periods by comparison with Figure 5, the variation of average periods with wave heights.

It can be seen from these figures that the highest wave occurrence is with 3.0-3.35 m (10-11 ft.) waves with a period of 7-8 seconds.



AVERAGE SEA SPECTRA - NORTH ATLANTIC

FIGURE 4



VARIATIONS OF AVERAGE
PERIODS WITH WAVE HEIGHTS

FIGURE 5

3.0 DEVELOPMENT OF A PREDICTOR EQUATION

To analyse the effect of different bow form parameters on the ice breaking resistance of the hull, it is necessary to produce a predictor equation. The form of the predictor should include all the parameters associated with ice resistance. Table 14 shows some of these.

Of the parameters listed in Table 14, ice thickness and ship/ice friction coefficients are perhaps the most significant. The flexural strength components, although important in model testing, are not thought to be significant at full scale. The ice parameters of forebody form and forebody block coefficients are thought to be the most critical vessel parameters. The vessel's beam is also an important parameter. The theoretical approach to predictor equations was developed by early research due to the lack of model and full scale data and to some extent is still being pursued by authors, such as Milano (ref. 2), who have developed a resistance predictor equation based on the ice breaking energy.

The semi-empirical method, however, is the most popular. Perhaps the best known equation, developed by Kashteljan, contains the three primary ice resistance components that are believed to make up the total ice resistance:

$$R_T = R_1 + R_2 + R_3 + R_0$$

R_1 = Ice Breaking Component

$= K_1 B \sigma h \mu_\theta$

R_2 = Ice Inertial Component (turning, submerging)

$= K_2 \rho h^2 \mu^2$

R_3 = Velocity Component

$= K_3 B^n h v / n$

R_0 = Open Water Resistance

The relative importance of the components (i.e. Ice Breaking, Ice Inertial and the Velocity Component) which make up the total resistance is not yet fully understood.

Figure 6 shows a number of authors and their prediction of how these three resistance components contribute to the total ice resistance.

The proportioning of total resistance into components is clearly a point of some contention. During 1978 Arctec Canada Ltd. conducted some work on behalf of the "Transport Canada Research & Development Centre" (ref. 4), now known as Transportation Development Centre, to analyse ice breaking technology at the time, and compiled a set of full scale and model scale data. From this data a non-dimensional predictor was generated based upon parametric grouping regressed from the compilation of data.

THE ICE		THE ICEBREAKER	
Ice Thickness	(h)	Stem Angle	(γ)
Ice Strength	(σ)	Waterline Entrance Angles	(α)
Ice Modulus of Elasticity	(E)	Waterline Flare Angle	(β)
Mass Density	(ρ)	Beam	(B)
Friction Coefficient	(f)	Draught	(T)
		Length	(L)
		Displacement	(Δ)
		Fore Body Block Coefficient	(C_{bf})
		Ship Speed	(V)

PRIMARY CHARACTERISTICS AFFECTING ICE RESISTANCE

Table 14

AUTHOR	ICE RESISTANCE COMPONENT		
	R_σ(%)	R_I(%)	R_V(%)
KASHTELJAN	6	88	6
WARTSILA 1974	0	32	68
ARCTEC PREDICTOR	8	60	32
EDWARDS et al 1976	16	24	60
LEWIS et al 1970	4.2	67.8	28

RELATIVE IMPORTANCE OF ICE RESISTANCE COMPONENTS
BY A NUMBER OF AUTHORS

Figure 7

The result was:

$$\frac{R}{\gamma_1 B h^2} = 0.727\mu_{12}^{0.965} (L/B)^{1.036} (\tan \gamma_0)^{0.332} (\cos \beta_s)^{-0.678}$$

$$+ 0.363\, C_{bf}^{2.92} (\tan \gamma_i)^{0.841} \cos \beta_T^{14.54} \frac{\sigma}{\gamma_i h} \frac{V}{\sqrt{gh}}$$

$$\mu_{12} = \mu_1 + 1.17\, \mu_2$$

R = Total resistance

γ = Ice weight density

L = Ship length

B = Ship beam

h = Ice thickness

μ_1, μ_2 = Geometric friction coefficients

γ = Bow stem angle

β_s = Minimum flare

σ = Ice flexural strength

V = Ship speed

Melville studied this expression and following an in-depth analysis, modified the expression to reflect both the full scale data collected from the ARCTIC and current ice breaking technology research. The resulting expression was:

$$R_T = R_I + R_V + R_T + R_0$$

R_I = Inertial resistance $= 0.2886\mu_{12}^{0.965} (L/B)^{1.036} (\cos\beta)^{0.678} h^2 gB$

R_V = Velocity component $= 351\, C_{bf}^{2.92} (\cos\beta)^{14.54} VBh^{1.436} / \sqrt{g\rho}$

R_T = Strength component $= 0.05\, \sigma Bh$

R_0 = Open water resistance $= 1.1943\, V^3$

This expression better represents the M.V. Arctic full scale data whilst retaining the parametric combinations regressed from the "Arctec Canada Ltd." work.

4.0 REDESIGN OF BOW FORM

Together with the predictor equations, an analysis of the α and β angles plotted against non-dimensional length was also conducted.

Figure 7 shows a number of curves of existing or planned ice-breakers which have been through model or full scale tests. The α and β angles (defined in Figure 7) have been plotted against a scale of non-dimensional forebody length.

Of the vessels shown, the HANSEN (Northcumberland Ferry design) is perhaps the best ice-breaker.

The MOSKVA is designed with particular attention paid to obtaining low waterline entrance angles and less emphasis on the high frame flare angles. The MOSKVA is reported to perform well.

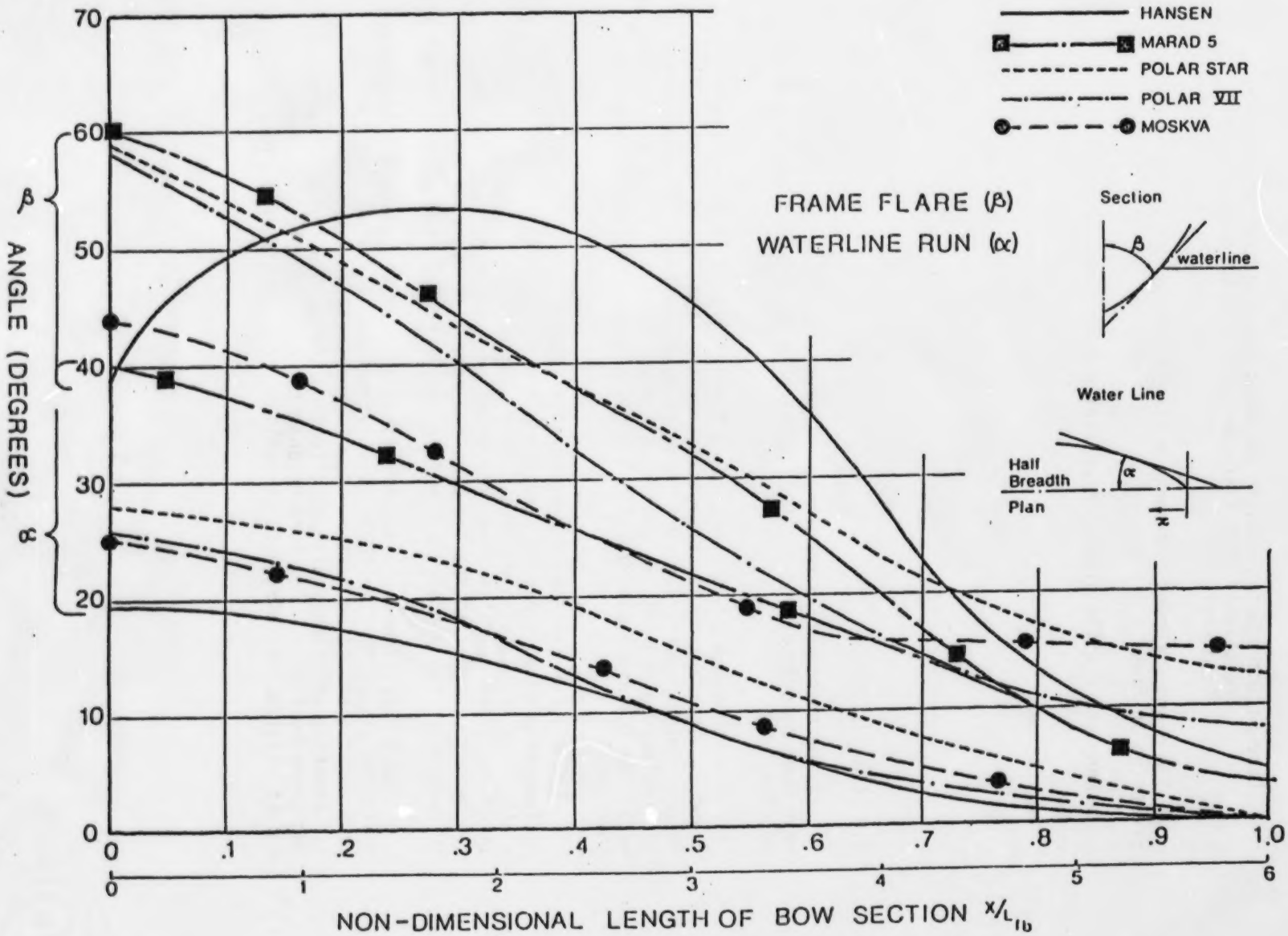
The MARAD 5 is a Finnish design, wall sided bulk carrier. The design emphasised high β angles and compromised on the α angles. The β angles as a result, are comparable to the POLAR VII, but because of the high α angles the vessel is not such a good ice-breaker.

By analysing these curves and from model test data, it can be seen that high β angles associated with high changes in α, result in a better ice-breaker. This can be generalized by saying that the effective shoulder should have high frame flare angles to ensure that in the area of maximum beam, breaking and not crushing is taking place.

The question of crushing can be raised with specific regard to the ARCTIC. Figure 8 shows the ARCTIC and compared with a number of other hulls it can be seen that the ARCTIC's shoulder area has a relatively low frame flare.

The design process progressed through 5 stages to develop 5 optional hull forms:

Case 1: Existing M.V. ARCTIC
Case 2: Maintaining β (frame flare angles) to maintain open water and seakeeping abilities.
Reducing α (waterline entrance angle) to improve ice clearing efficiency.
Stem angle reduced to 25° to reduce the Forebody Block Coefficient.
Case 3: Maintaining α angles and increasing β angles.
Stem angle 15°.
Case 4: Maintaining β angles and redistributing α angles to achieve high α angle change with high β angles.
Case 5: Maintaining α angles and modifying β angles to achieve high angles directly associated with high α angle gradient. (Hansen type form).
Stem angle 20°.



FRAME FLARE AND WATERLINE RUN ANGLES

FIGURE 7

Case 6: Introducing knuckle at about the 10m buttock to allow relatively high flare angles close to maximum beam. Stem angle 15°.

The α and β curves for these hulls and the original hull are presented in Figures 8 - 13.

Body and Profile plans are presented in Figures 14 - 25.

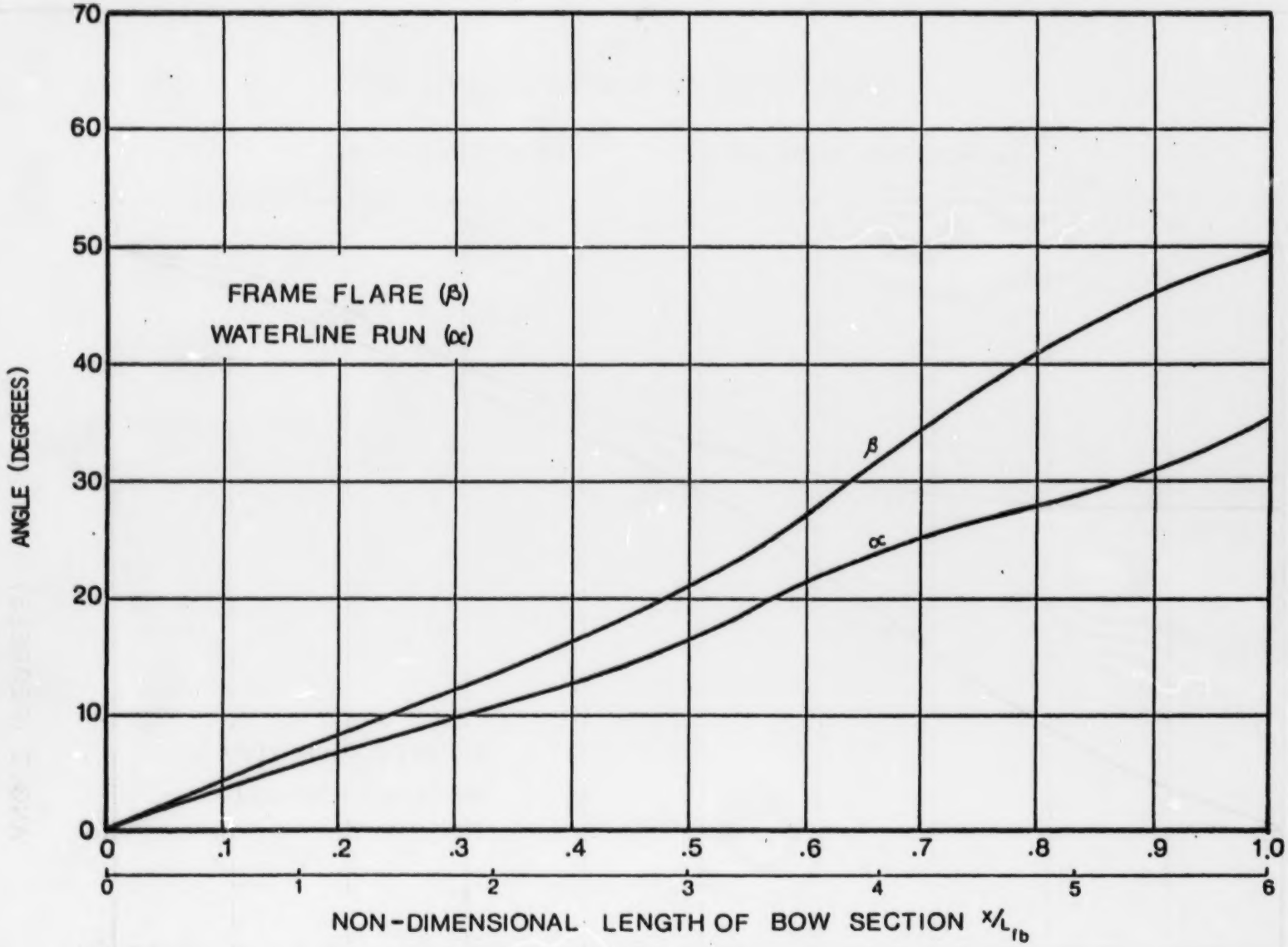
5.0 CONCLUSIONS

Using these hull parameters, the predicted resistance for each have been calculated and plotted, together with the full scale test results.

The bow forms 2 - 5 represent a family of hull forms ranked 5, 3, 4 and 2. The ranking is consistent over the whole speed range. The forebody block coefficient was found to have a strong influence on the ice resistance and this is seen in the bows 3 and 4. Bow 4 has better waterline (α) angle distribution but has a higher block coefficient than bow 3.

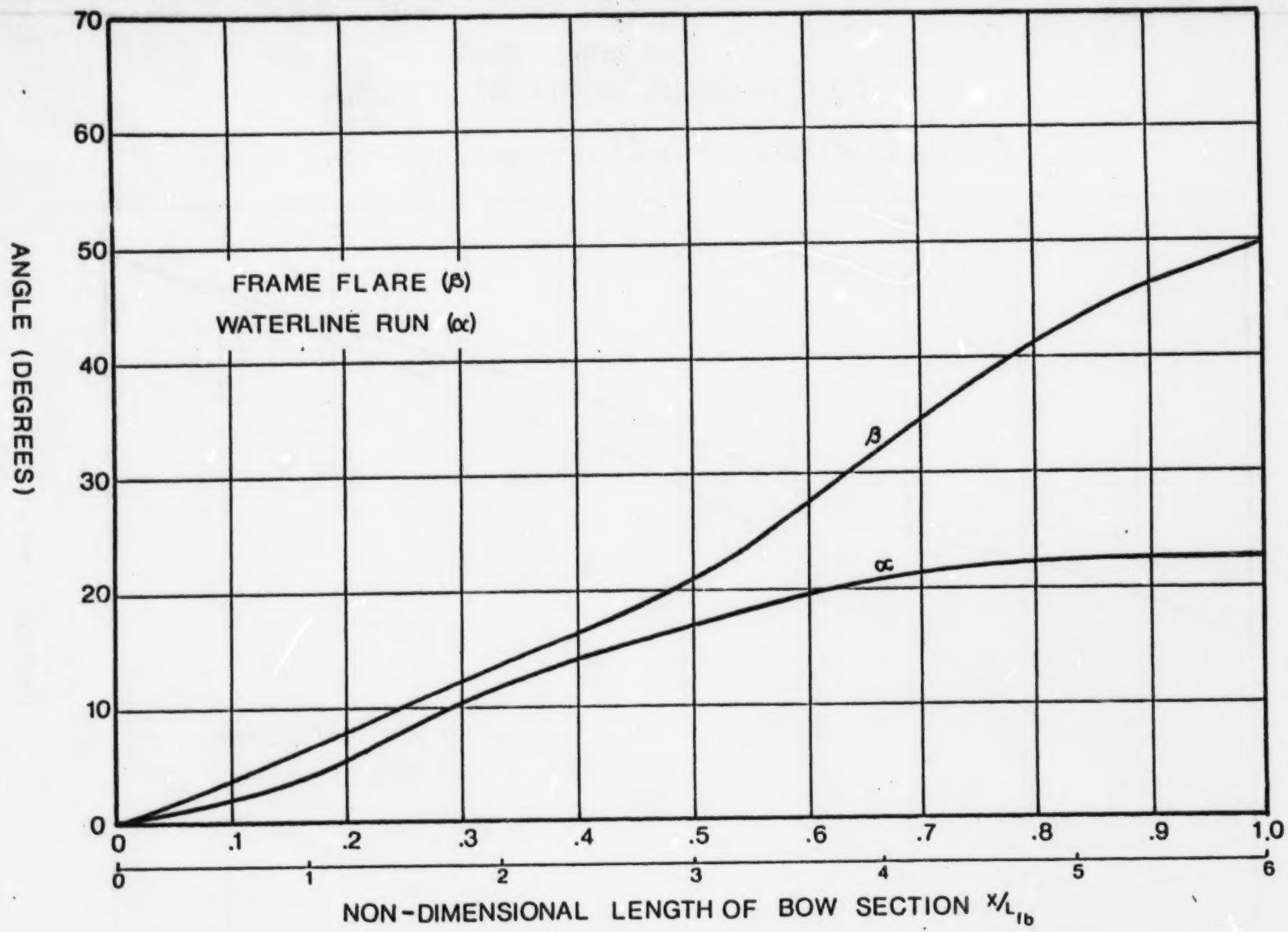
Bow 6 is an attempt to achieve high flare angle as close to the maximum beam as possible by permitting the use of knuckles and an insert plate. The resultant bow shows a very slight benefit to the ice resistance using the Melville predictor equation. We do not believe that the benefit accrued in the ice breaking mode will overcome the increase in open water resistance which will probably result from using this bow.

The bow forms and preliminary lines were presented to TDC and following discussions on their relative merits it was decided that bows 2 and 5 should be tested. Bow 2 represents an improvement of ice breaking efficiency without affecting the open water or seakeeping characteristics. Bow 5 represents the best ice breaking form whilst still maintaining good streamlines and knuckle free flow.



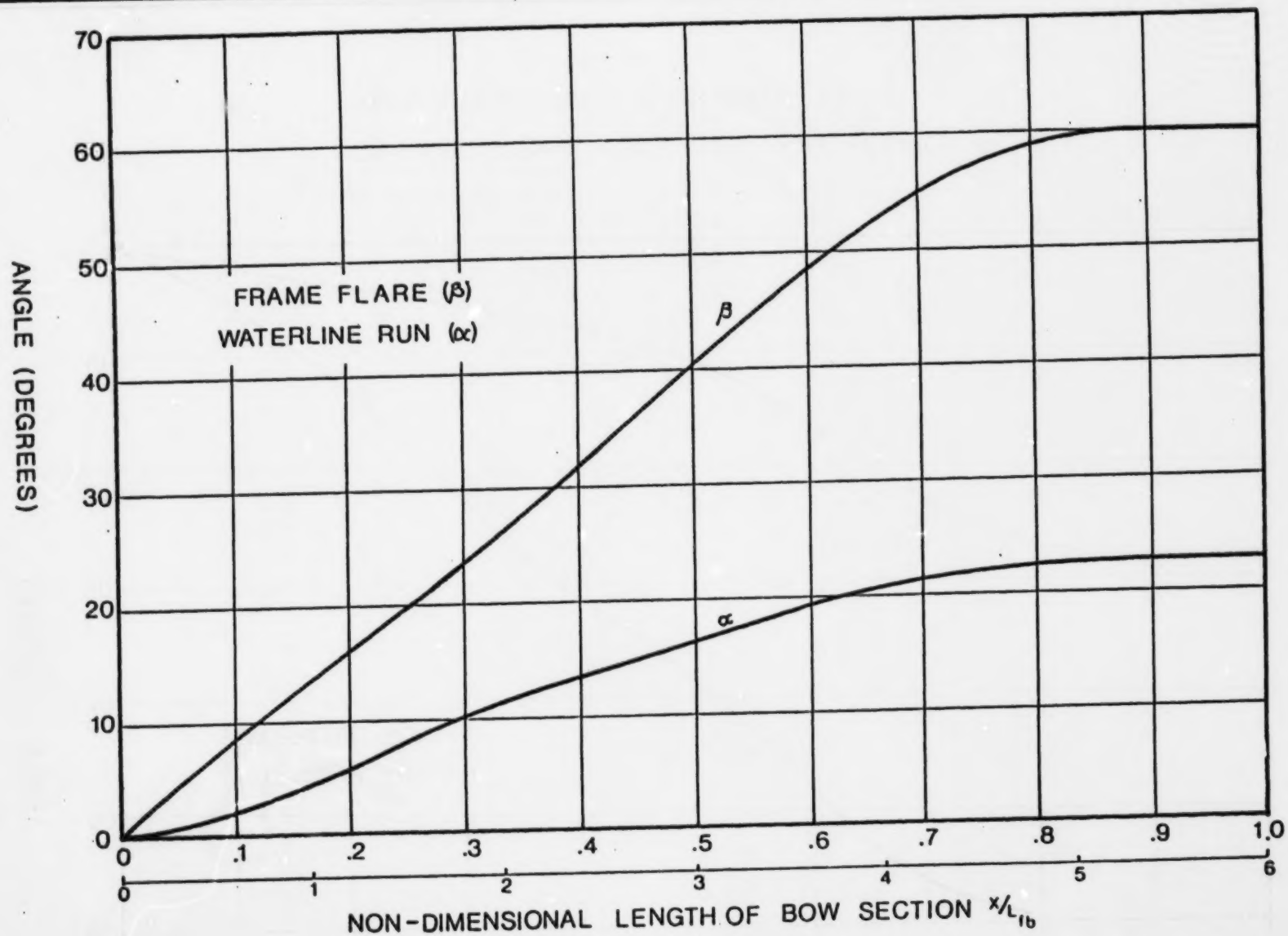
FRAME FLARE AND WATERLINE RUN ANGLES - CASE 1

FIGURE 8



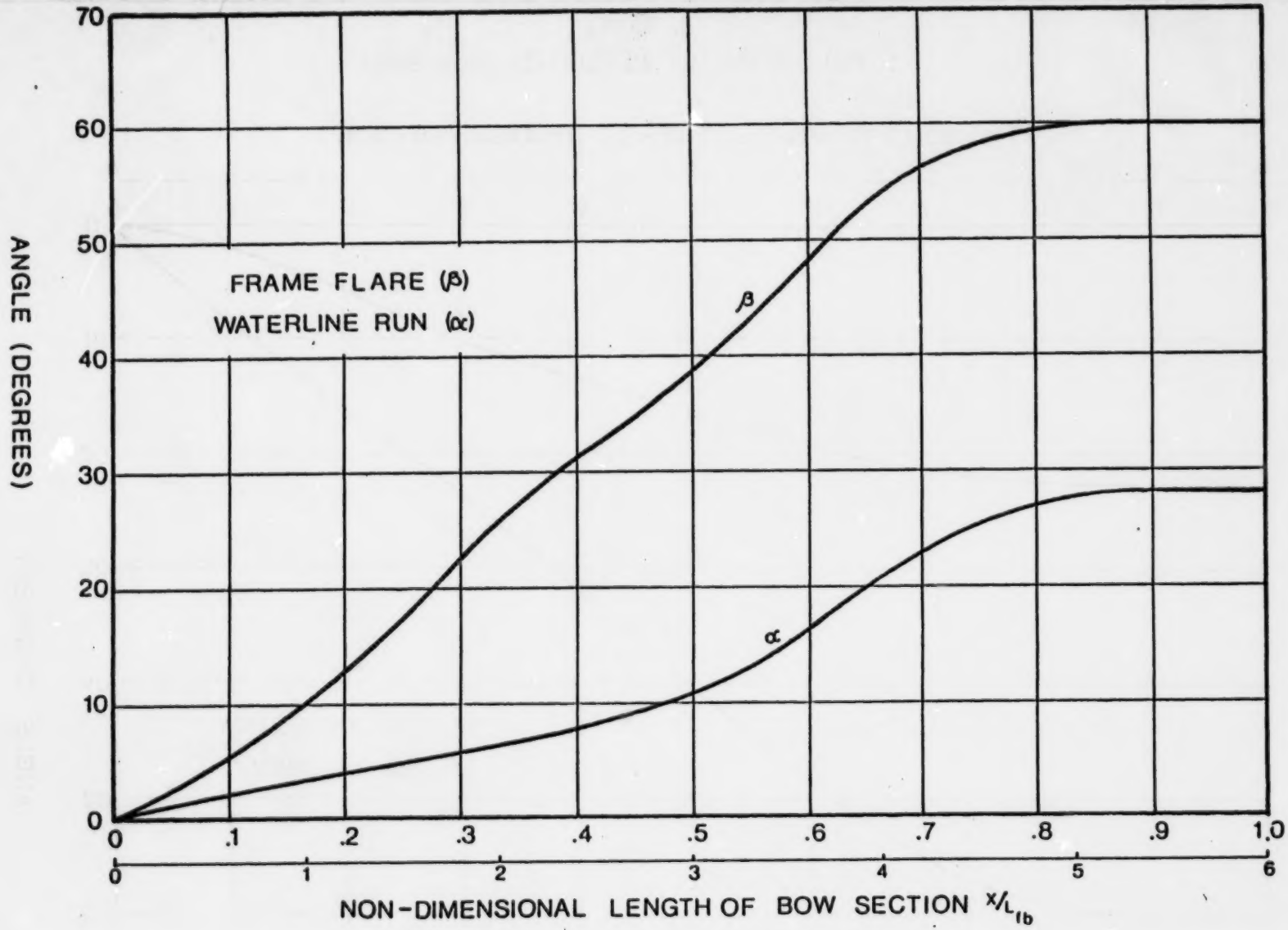
FRAME FLARE AND WATERLINE RUN ANGLES - CASE 2

FIGURE 9



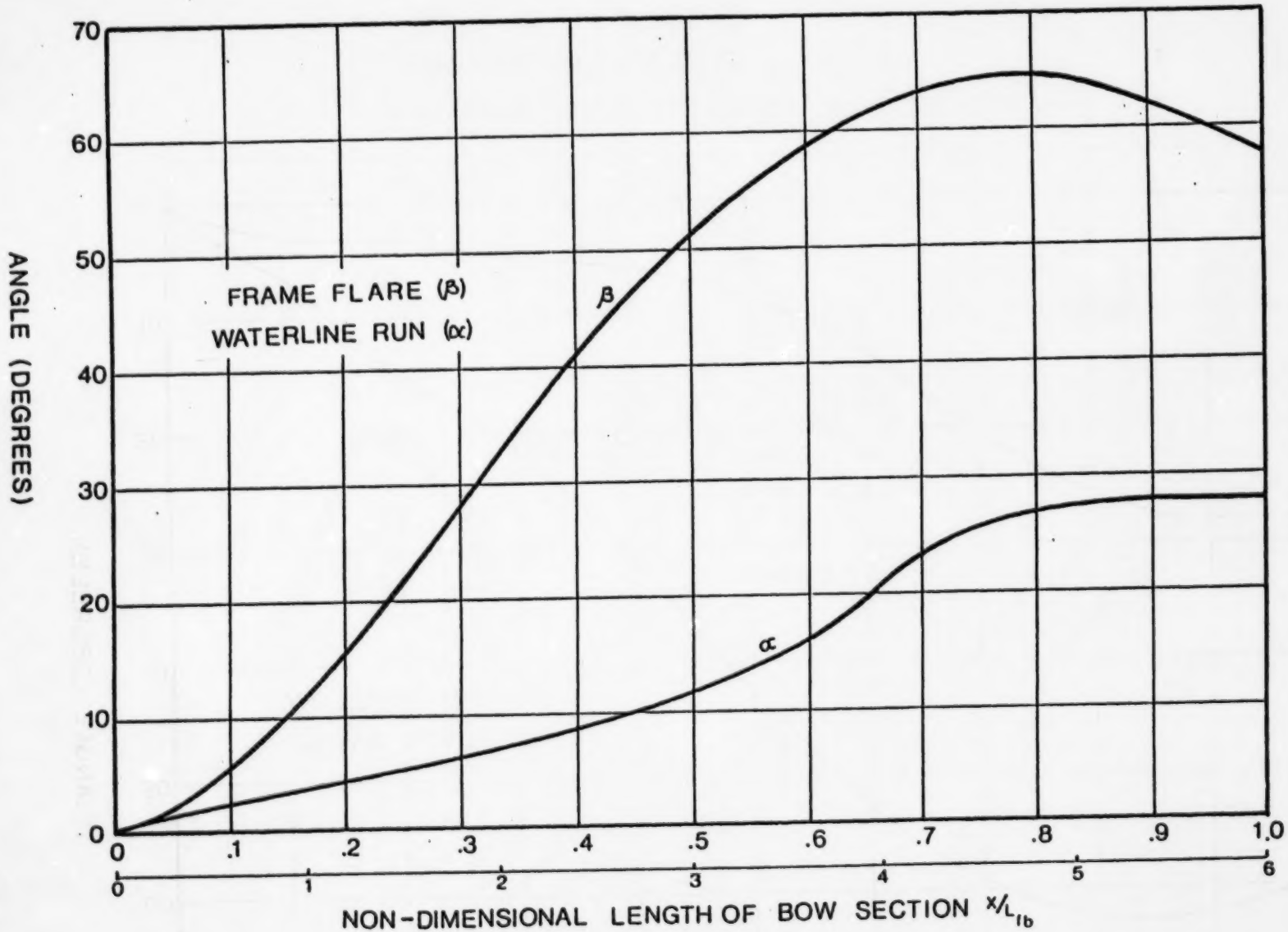
FRAME FLARE AND WATERLINE RUN ANGLES - CASE 3

FIGURE 10



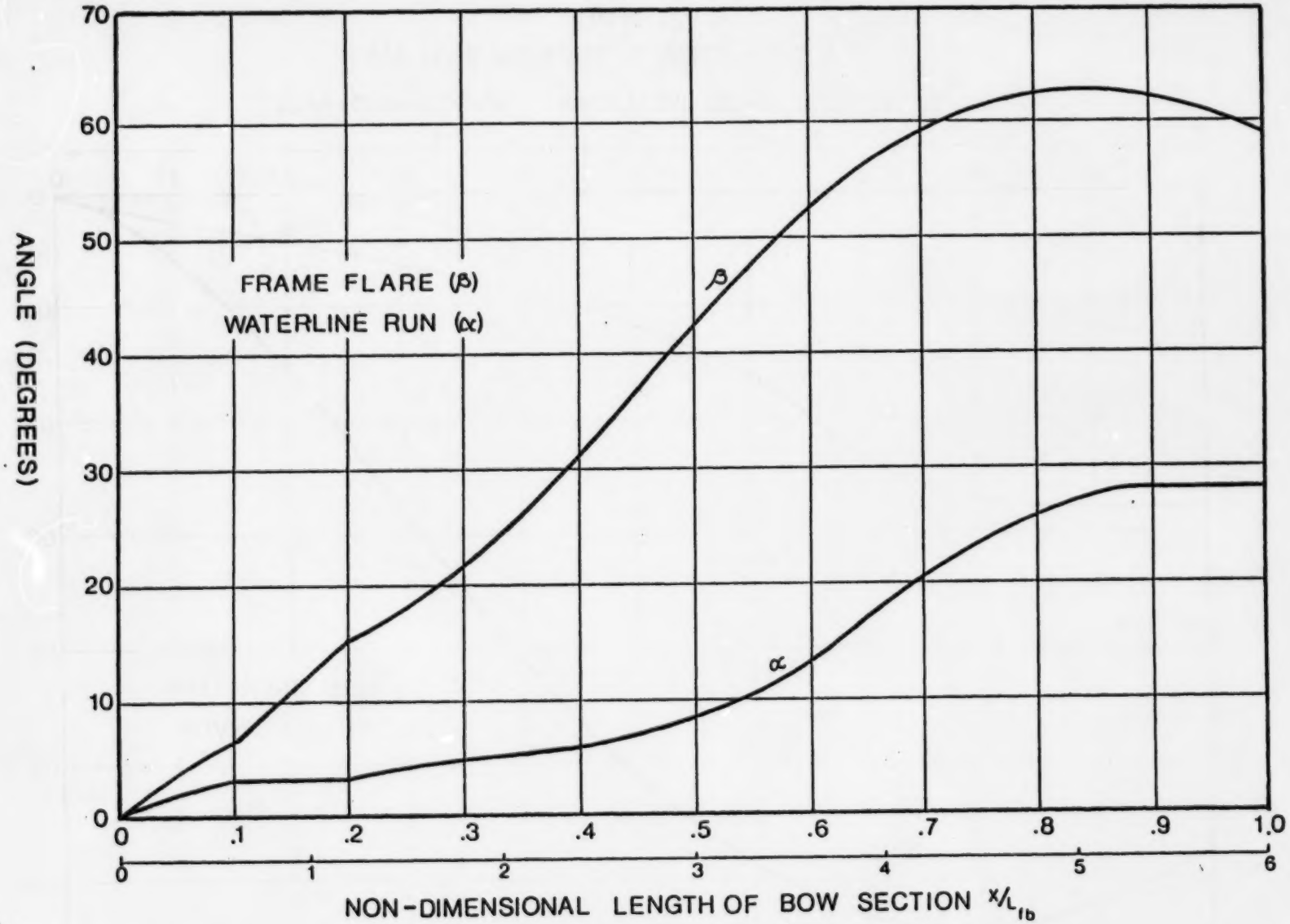
FRAME FLARE AND WATERLINE RUN ANGLES - CASE 4

FIGURE 11



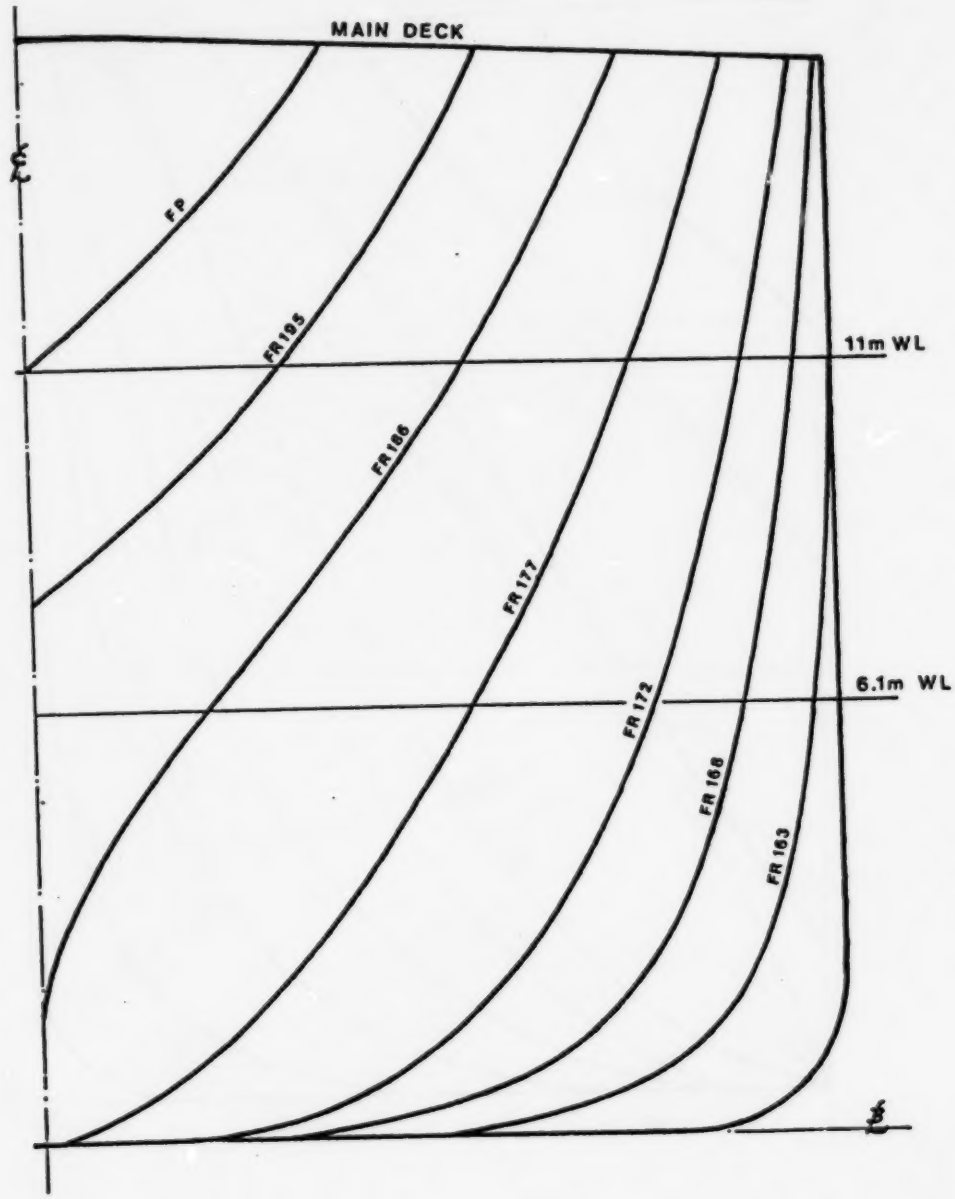
FRAME FLARE AND WATERLINE ANGLES - CASE 5

FIGURE 12



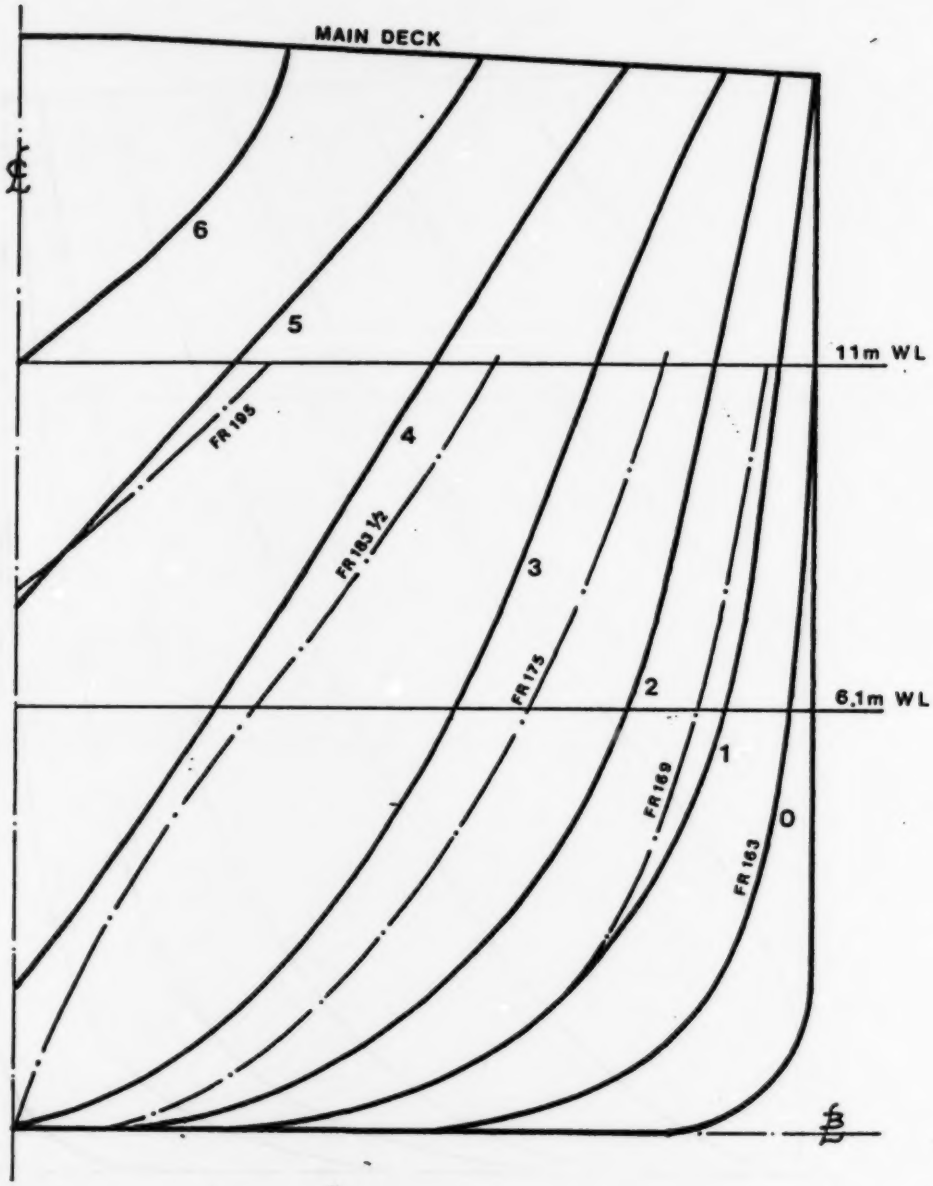
FRAME FLARE AND WATERLINE ANGLES - CASE 6

FIGURE 13



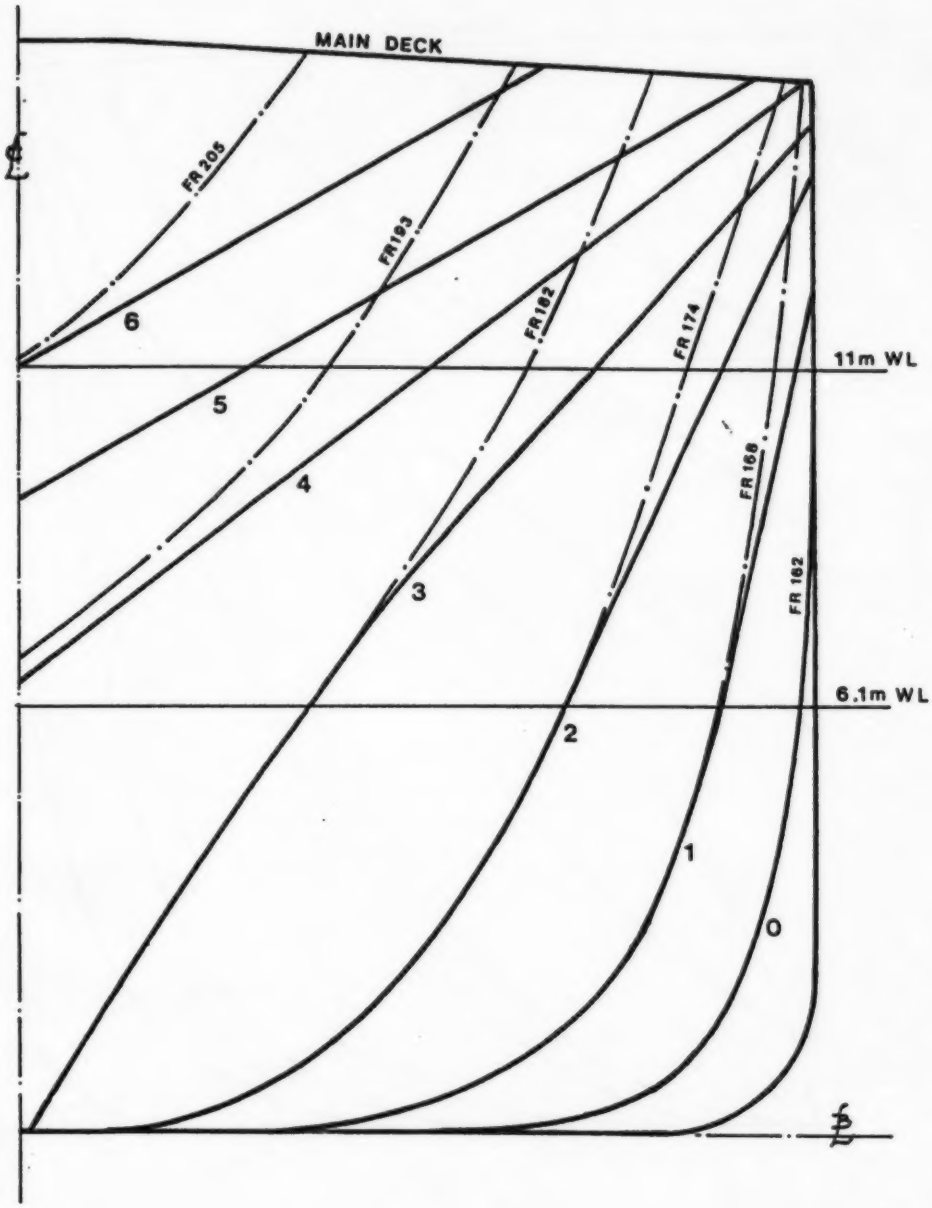
M.V. ARCTIC - EXISTING BOW
CASE 1 - BODY PLAN

FIGURE 14



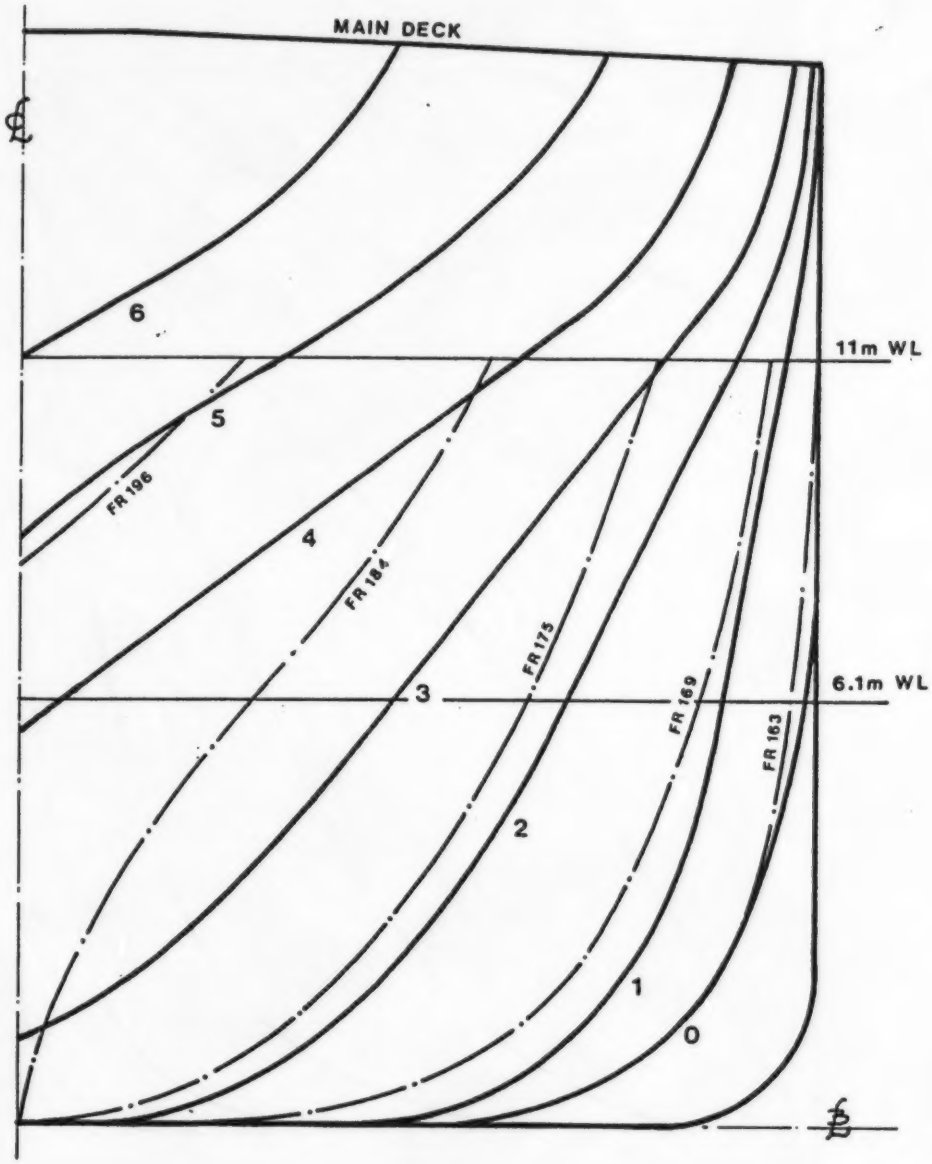
M.V. ARCTIC - MODIFIED BOW
CASE 2 - BODY PLAN

FIGURE 15



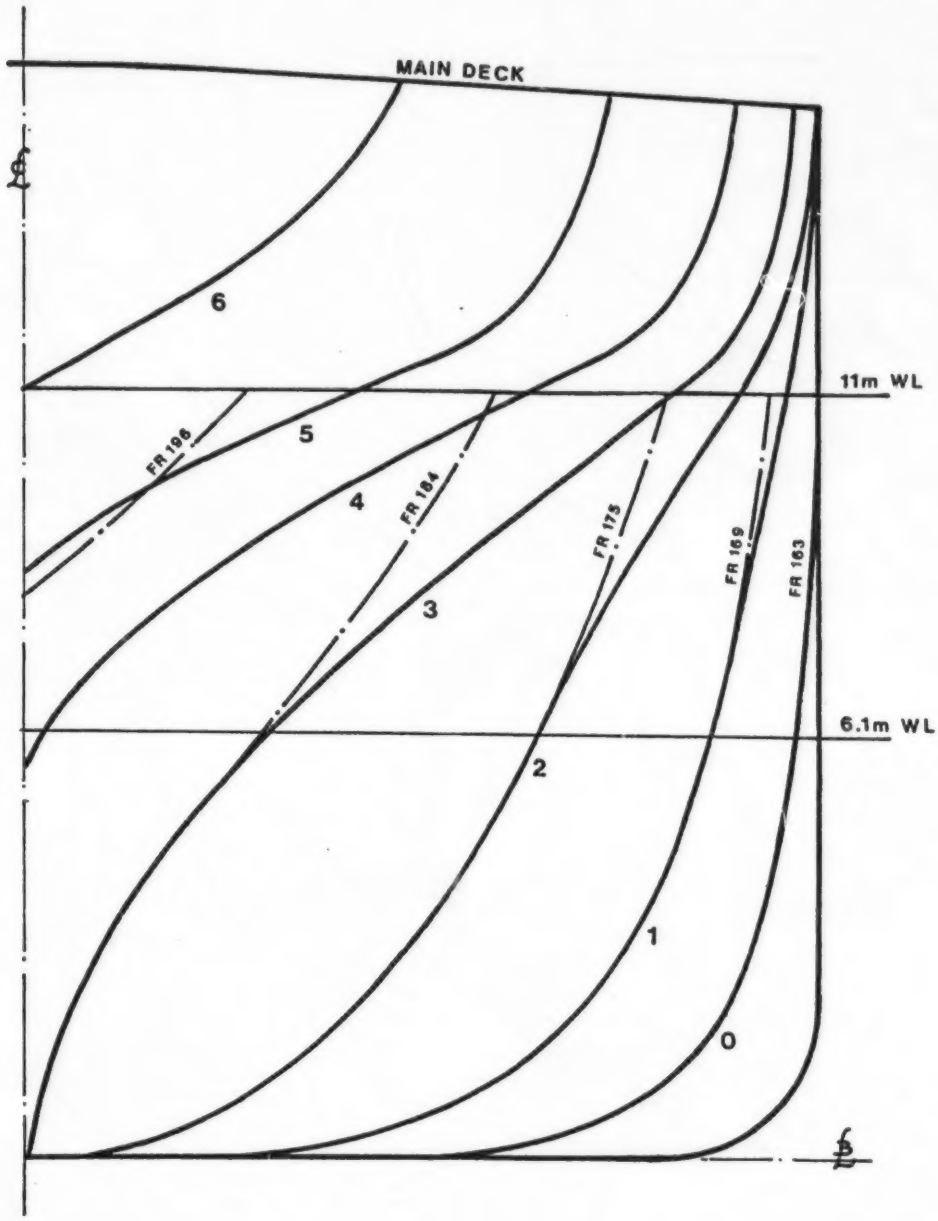
M.V. ARCTIC - MODIFIED BOW
CASE 3 - BODY PLAN

FIGURE 16



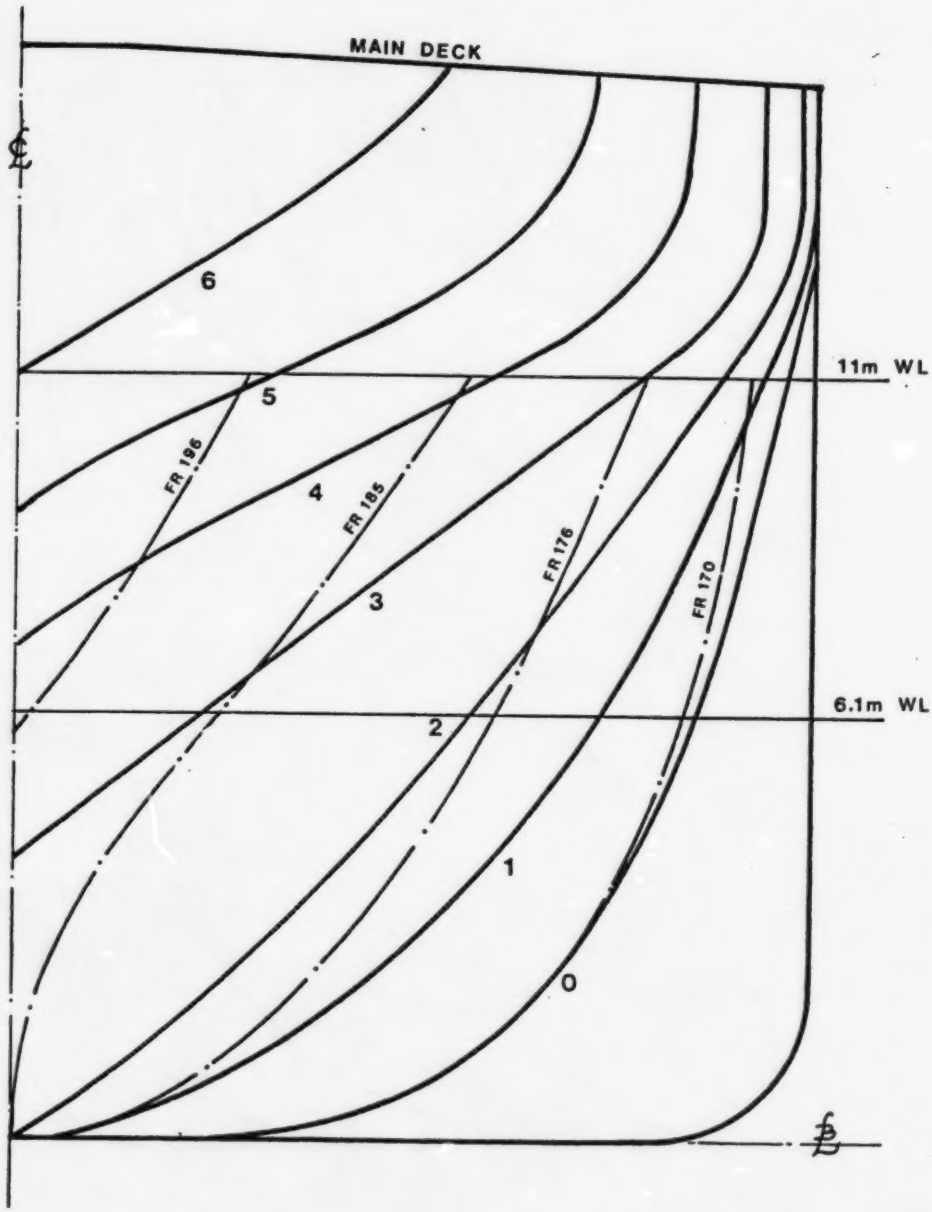
M.V. ARCTIC - MODIFIED BOW
CASE 4 - BODY PLAN

FIGURE 17



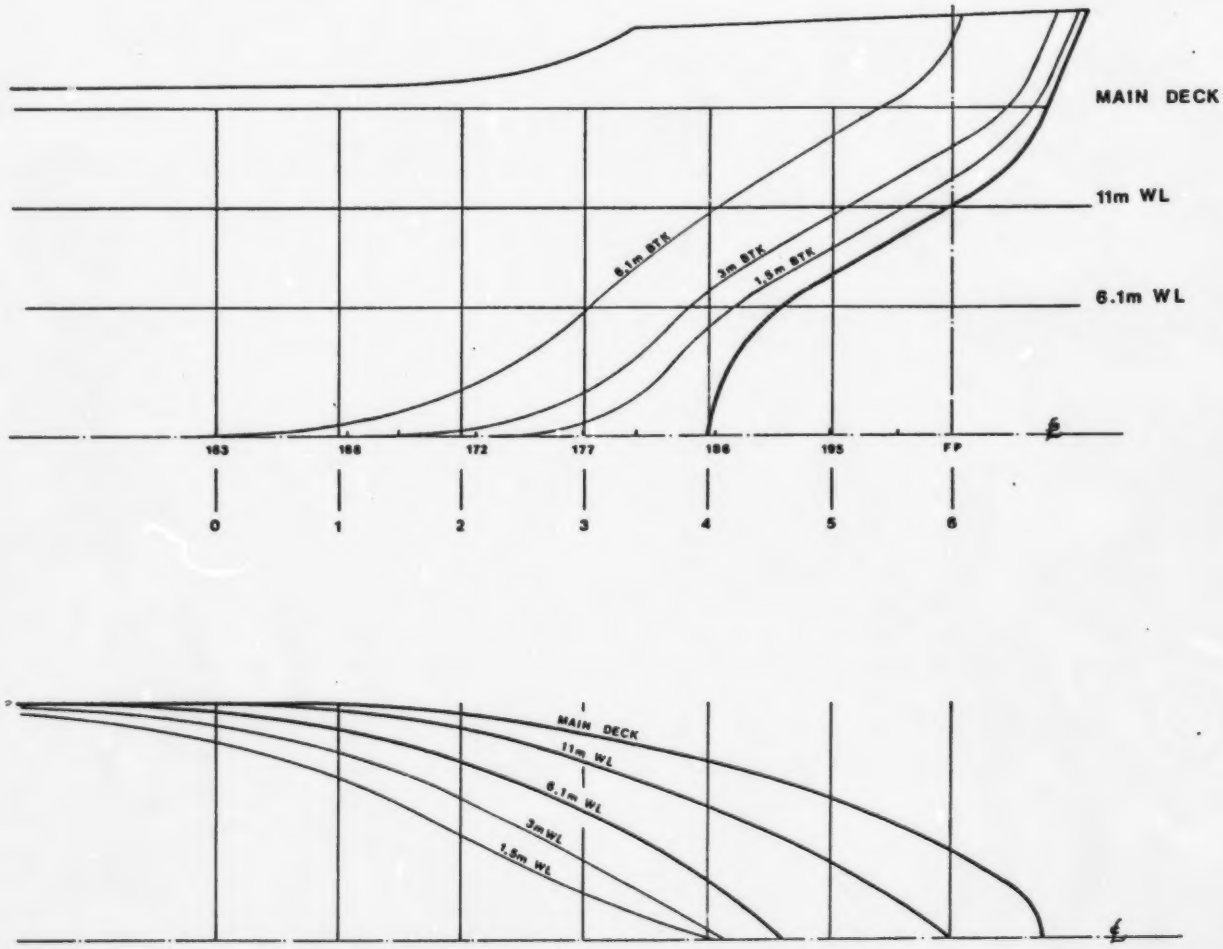
M.V. ARCTIC - MODIFIED BOW
CASE 5 - BODY PLAN

FIGURE 18



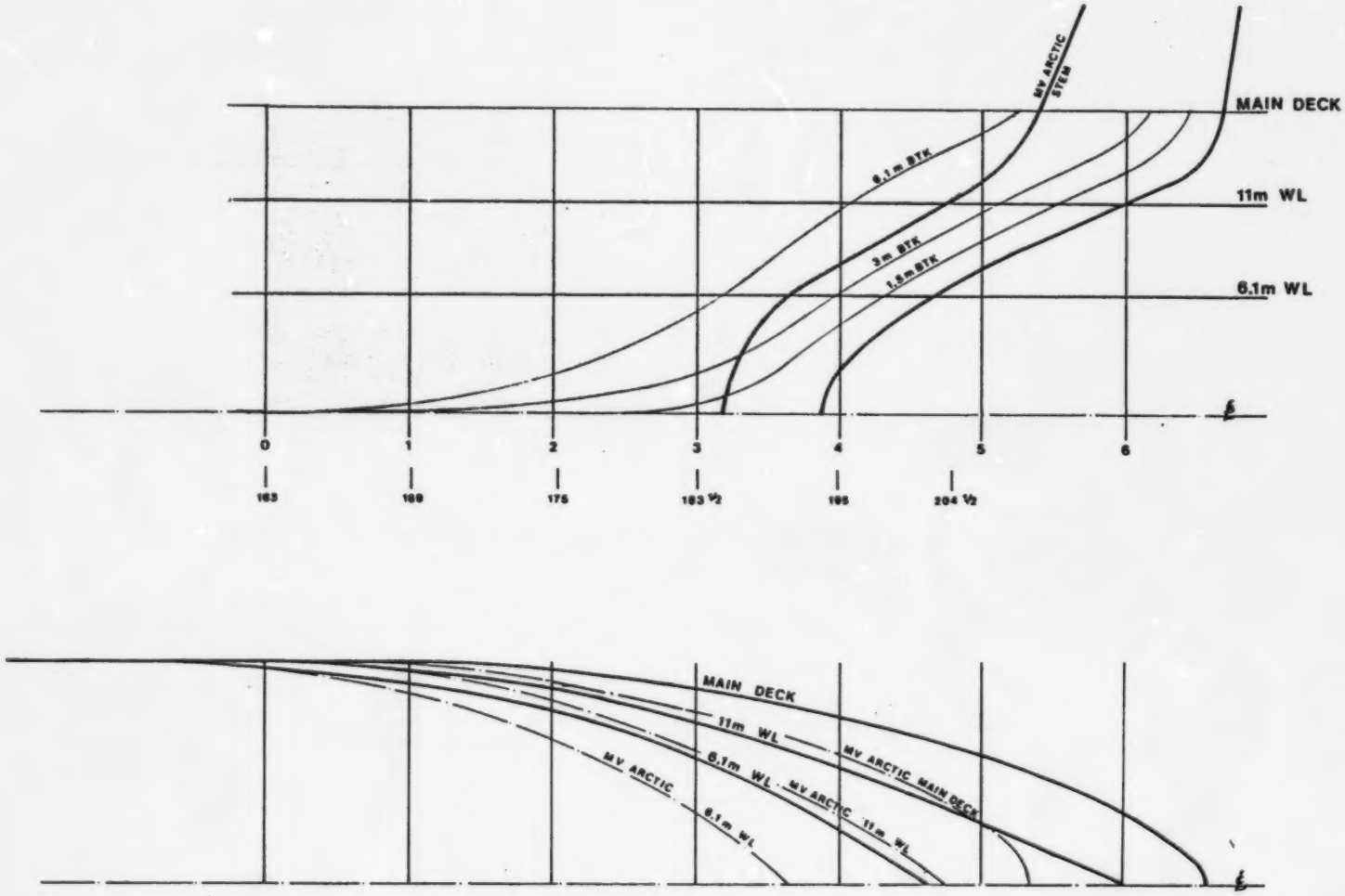
M.V. ARCTIC - MODIFIED BOW
CASE 6 - BODY PLAN

FIGURE 19



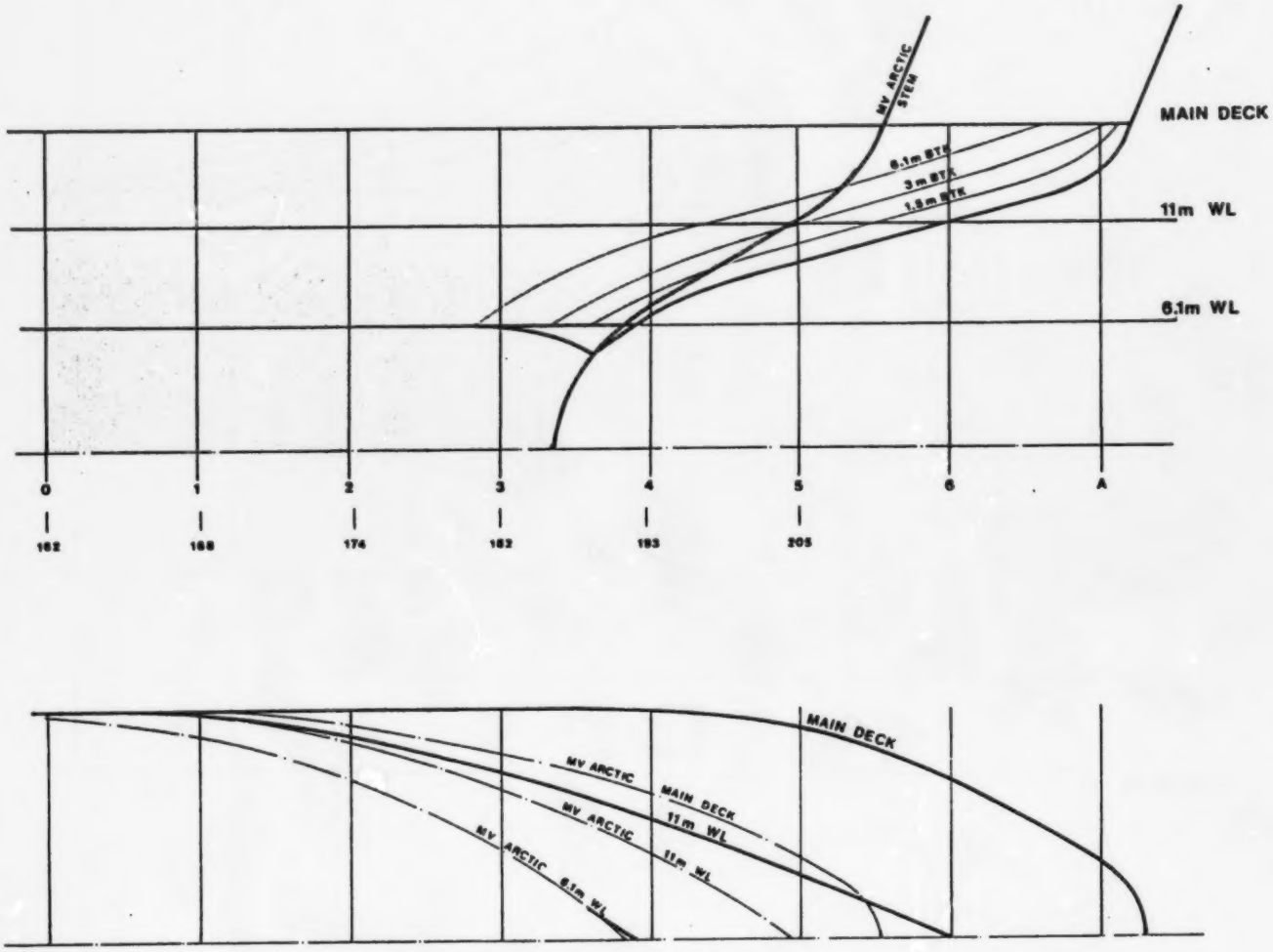
M.V. ARCTIC - EXISTING BOW - CASE 1 - LINES PLAN

FIGURE 20



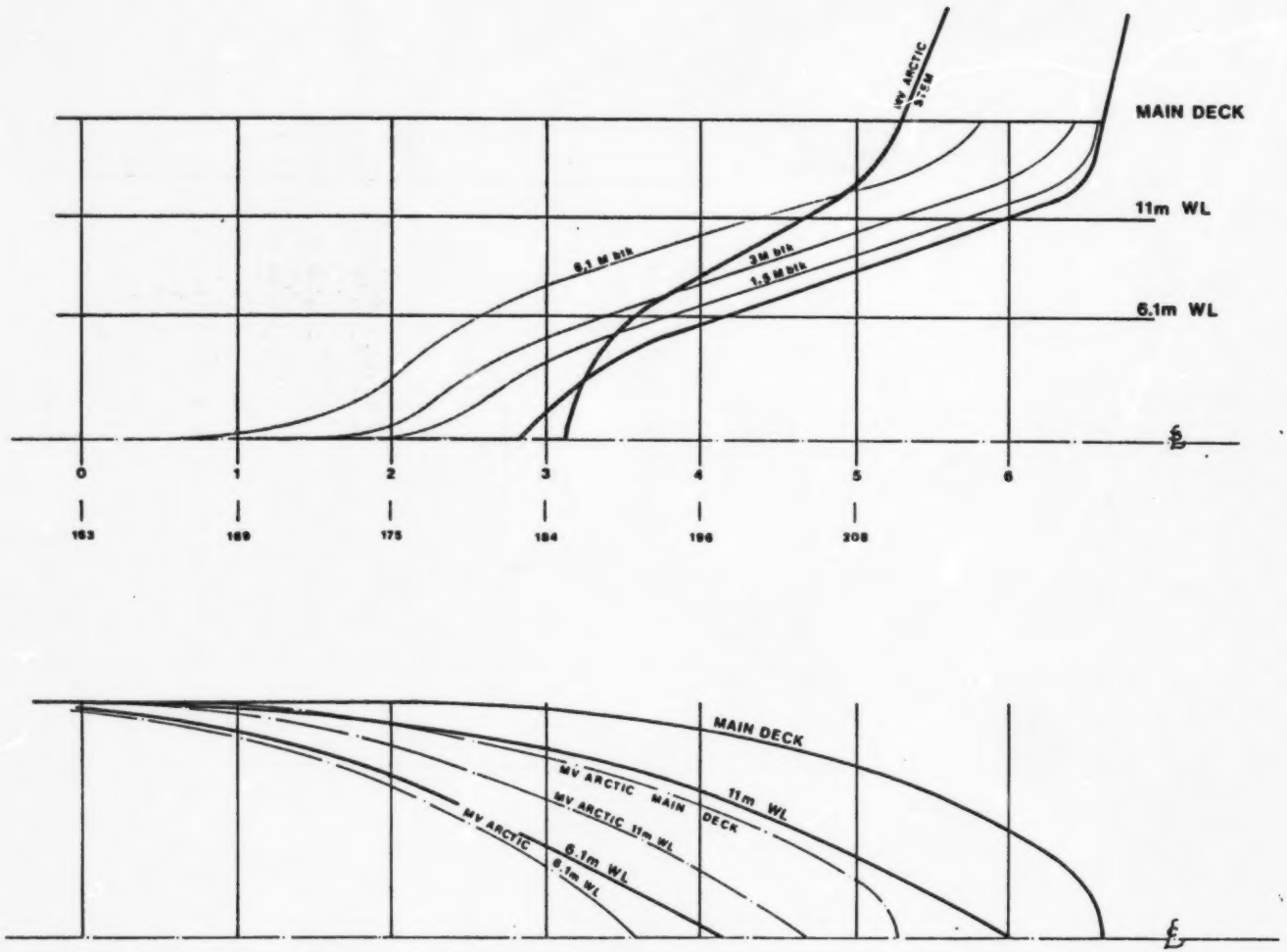
M.V. ARCTIC - MODIFIED BOW - CASE 2 - LINES PLAN

FIGURE 21



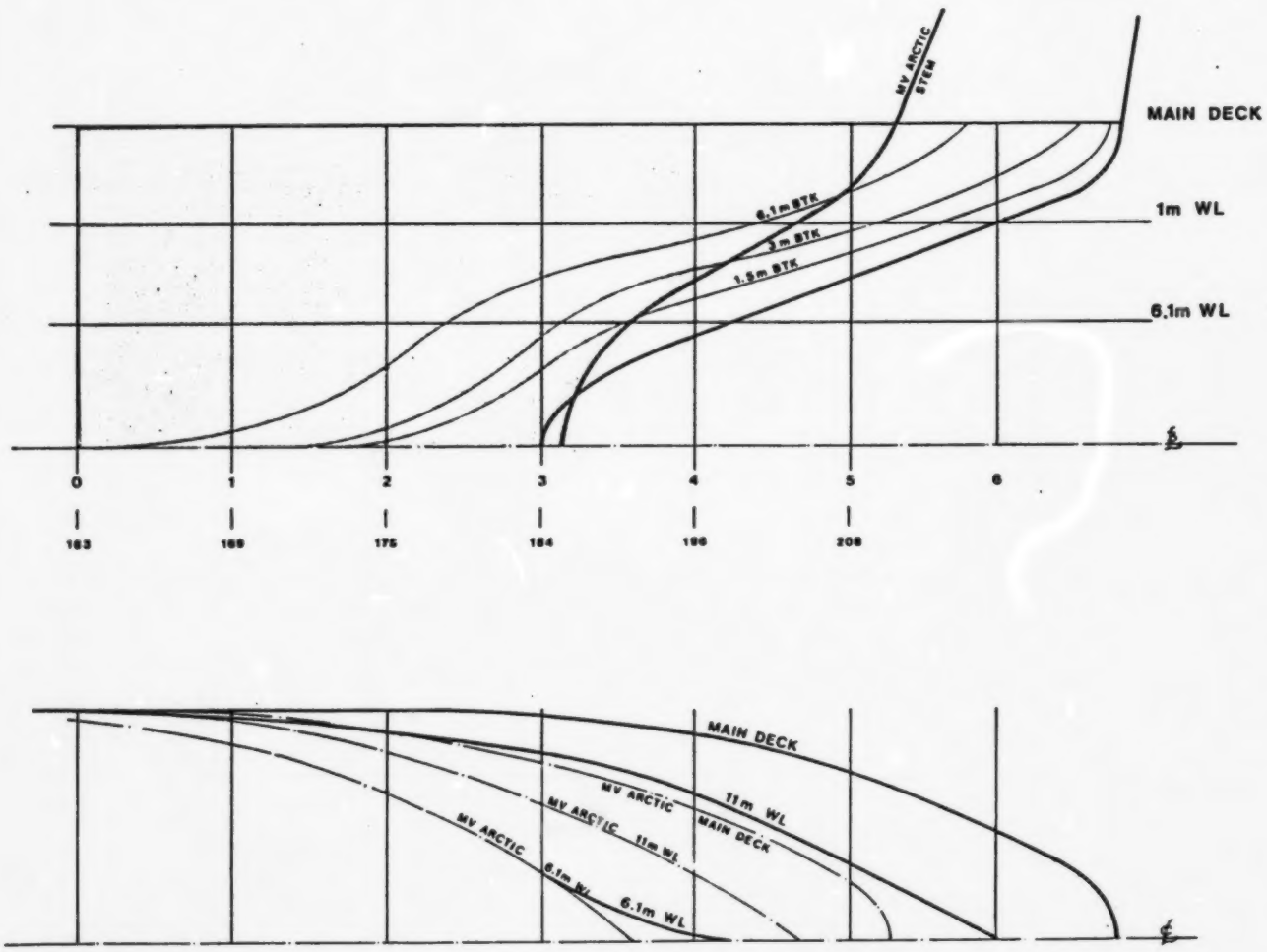
M.V. ARCTIC - MODIFIED BOW - CASE 3 - LINES PLAN

FIGURE 22



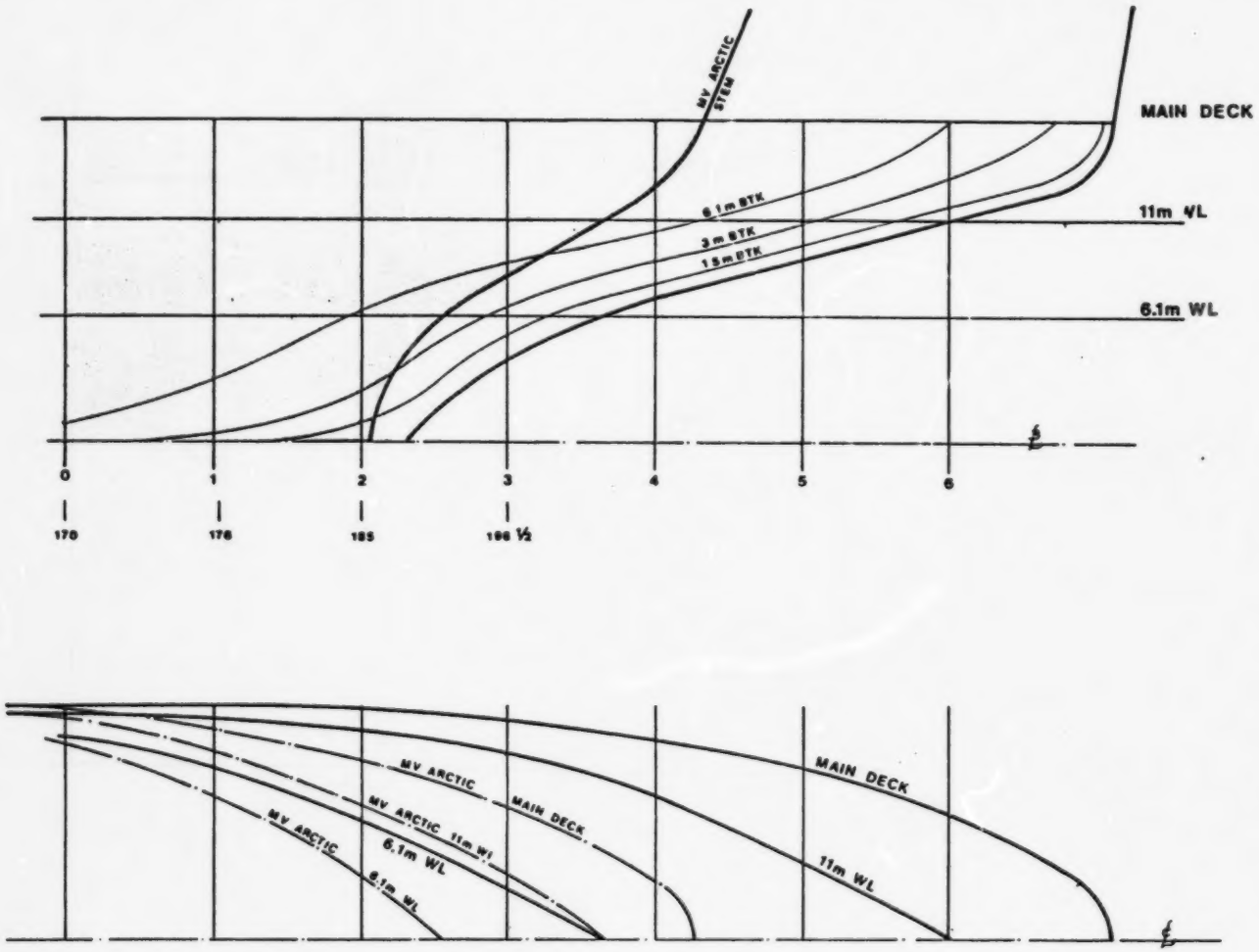
M.V. ARCTIC - MODIFIED BOW - CASE 4 - LINES PLAN

FIGURE 23



M.V. ARCTIC - MODIFIED BOW - CASE 5 - LINES PLAN

FIGURE 24



M.V. ARCTIC - MODIFIED BOW - CASE 6 - LINES PLAN

FIGURE 25

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